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CALCULATIONS OF ENVIRONMENTS FROM LOW-YIELD NUCLEAR DETONATIONS--ETC(U)
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CALCULATIONS OF ENVIRONMENTS FROM LOW-YIELD NUCLEAR DETONATIONS (RAD9 CODE RESULTS)

Kaman Sciences Corporation
P.O. Box 7463
Colorado Springs, Colorado 80933

June 1976

Final Report for Period 1 March 1976—30 June 1976

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Material Profiles	Velocity Contours

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Defense Nuclear Agency has supported an extensive program to better define the blast, thermal and initial nuclear radiation environments associated with low-yield shallow buried nuclear device detonations. This report and the appendix include detailed results of 2-D rad-hydro computations for two geometries of interest using the KSC version of the RAD9 Code. → next page

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20. ABSTRACT (Continued)

cont.
The RAD9 Code is briefly described and results are shown for a 1-KT source at burial depths of 0.5 and 3.0 meters. Because of the limitations in the scope of work, additional tasks are suggested which would provide information on the effect of yield on air blast and sensitivity of results to equations of state.

PREFACE

It is a pleasure to acknowledge the technical assistance extended by Capt. Jerry Stockton, SPSS, and Mr. Mort Rubenstein, SPAS, both of DNA. In addition, the cooperation and help supplied by Mr. Jeff Thomsen, ERDA-Livermore, and Capt. Mark Fry, AFWL, was much appreciated.

For Kaman Sciences, major contributions were made by Dr. Peter Snow and Mr. David Cruikshank. The outstanding assistance of Dr. Wallace Johnson, Computer Code Consultants, is gratefully acknowledged.

TABLE OF CONTENTS

1.0 INTRODUCTION

During the first three or four months of CY 1976, the Defense Nuclear Agency organized and funded an extensive program of one-dimensional and two-dimensional computer code calculations dealing with low-yield, shallow-buried nuclear device detonations. The main thrust of this effort was to better define the blast, thermal and initial nuclear radiation environments associated with such detonations. A secondary objective was to attempt to compare the results obtained from several different complex 2-D rad-hydro codes which are being run around the country.

In order to make these comparisons of code results meaningful, DNA requested that ERDA-Livermore generate the source tapes to be used by all the participants. Responding to that request, Livermore (Jeff Thomsen) supplied source tapes for each depth of burial considered.

As a portion of a Kaman Sciences' investigation for DNA of the test design for an underground cavity experiment (HURON KING), it became necessary for Kaman to perform 2-D rad-hydro computations for two of the geometries of interest. The computations were done using the KSC version of the RAD9 Code. This report presents some of the results of those two calculations.

Following this introduction, the RAD9 Code will be described briefly. Then, the principal results will be presented and discussed; for individuals who are interested in the detailed results, more data are included in the Appendix. The report concludes with some suggestions for further work, using the RAD9 Code.

2.0 DESCRIPTION OF THE RAD9 CODE

The Kaman Sciences' RAD9 Code is a two-dimensional multi-material hydrocode which treats material strength with elastic-plastic relations and handles radiation flow (and conduction) effects with a single-group greybody formulation. Hydrodynamic difference equations are explicit and accurate to terms of first order, while radiation is generally implicit. Massless tracer particles are used to define surface positions and move across the Eulerian grid, so that the code yields a Lagrangian-type definition of moving surfaces. The code is capable of handling up to nine materials with two materials per cell. Transfer of material between mixed Eulerian cells is effected by forcing a common velocity (and pressure) on the two constituents, computing the total increase in internal energy within the cell, and partitioning this energy between the materials by assuring that energy increments are proportional to fractional volumes occupied by the various materials. These fractional volumes are computed by dividing the mass of each material by its density.

Generally, Tillotson's equations of state are used in the code; however, in some calculations other analytic or tabular forms are used. A Brode fit to the Hillsenrath data has been used for air and tabular data from Sandia Corporation (CHART-D) has been employed for various materials, particularly those used in nuclear weapons. Greybody opacities used in the code are obtained from Heubner's (LASL) tabular data and they include line spectra.

3.0 RAD9 CODE RESULTS

Some selected results from the KSC RAD9 Code runs for the 0.5-meter and 3-meter depth of burial, 1-KT source, are presented in this section. First, the maps of the motion of the various materials in the problem are shown for specific times after the burst. Next, some temperature profiles are shown for the 3-meter calculation only, and, finally, the partition of energy between the soil and the air is presented in tabular form.

3.1 Material Profiles

The material profiles corresponding to the 0.5-meter DOB calculation are shown in Figures 3.1 through 3.3. The first profile at t = 0.175 msec (Figure 3.1) shows the characteristic shape of the early-time material "bubble". It should be noted that although the bubble is truly oblong in shape (larger vertically than horizontally), the distortion in shape is somewhat accentuated by the choice of scales on the plots. Reference to Figures 3.2 and 3.3, which show material profiles representative of later times, indicates that the profile evolves as if the source were expanding from a region 4 to 6 meters above the initial soil/air interface. It is also apparent that a large volume of soil is moved upward and outward at these relatively early times, supporting the expanding air blast pressure wave. Note that near the soil/air interface there is a cusp, which is again characteristic of a low air burst geometry rather than a buried burst geometry.

The material profiles corresponding to the 3-meter DOB calculation are shown in Figures 3.4 through 3.7. As one would expect, the profiles shown here for the deeper buried burst are significantly different from those shown for the

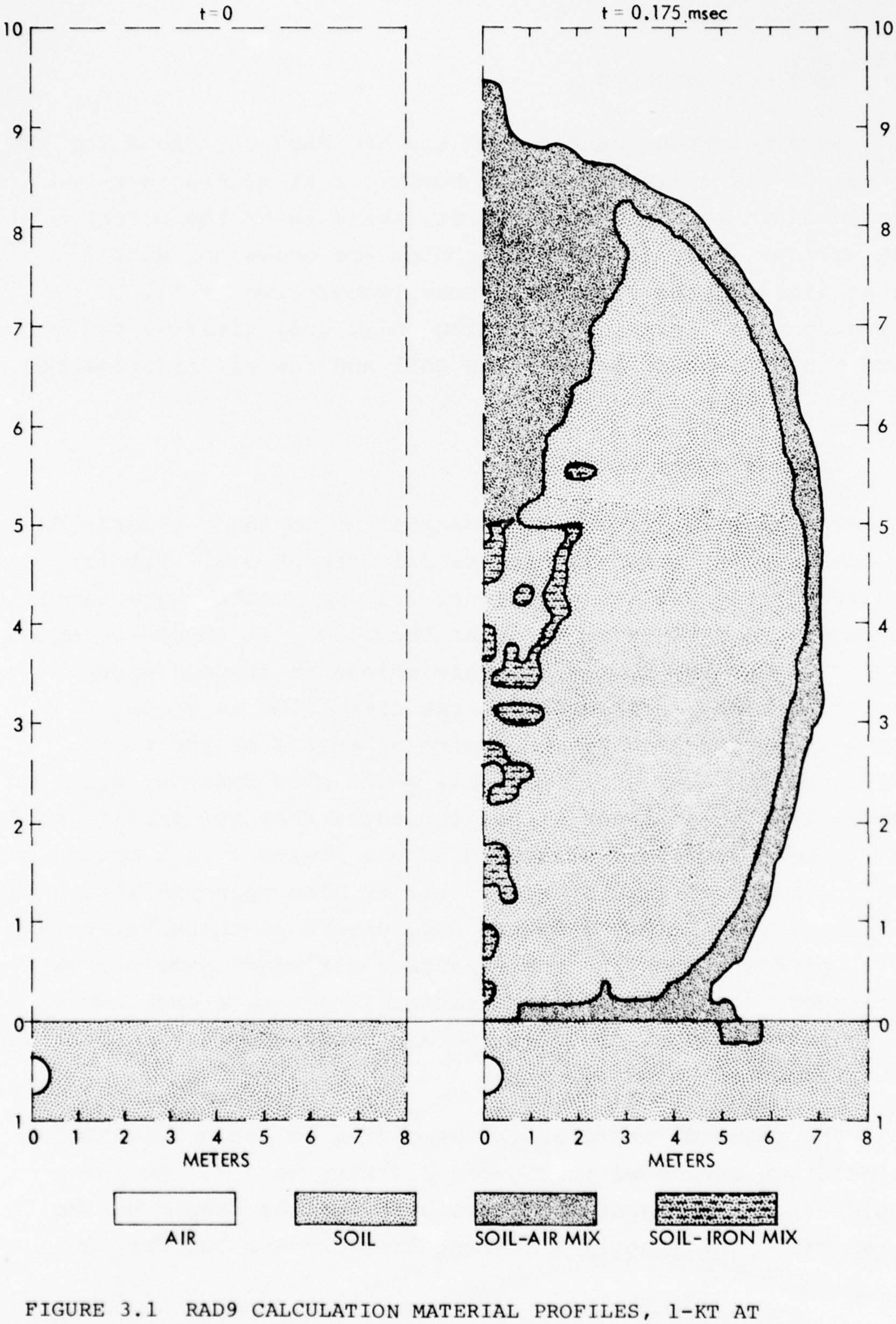

FIGURE 3.1 RAD9 CALCULATION MATERIAL PROFILES, 1-KT AT 0.5-METER DEPTH, t = 0 AND t = 0.175 MSEC

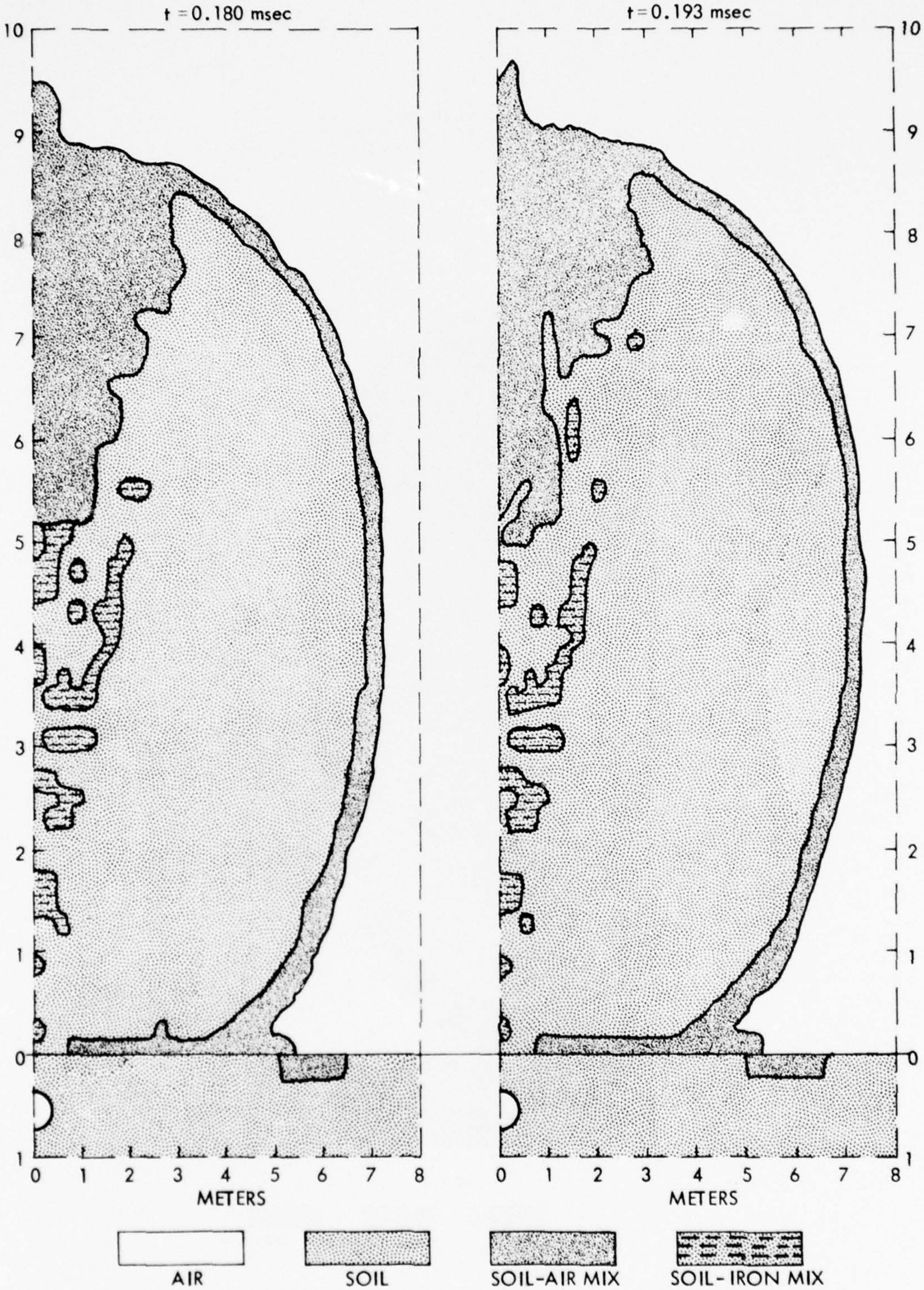

FIGURE 3.2 RAD9 CALCULATION MATERIAL PROFILES, 1-KT AT 0.5-METER DEPTH, t = 0.180 MSEC AND t = 0.193 MSEC

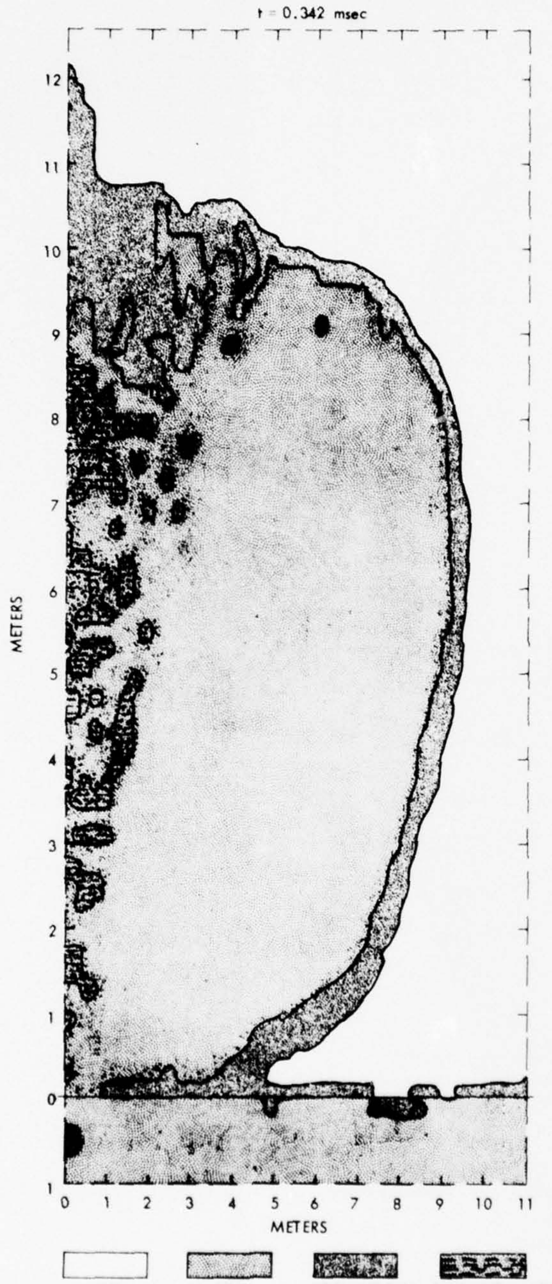

FIGURE 3.3 RAD9 CALCULATION MATERIAL PROFILE, 1-KT AT 0.5-METER DEPTH, t = 0.342 MSEC

0.5-meter case. The early-time expansion (Figures 3.4 and 3.5) is characteristic of the so-called "earth-piston" effect which has been observed often when large high-explosive (H.E.) charges are buried and detonated. For the later times (Figures 3.6 and 3.7), the piston appears to push up through the top and expand more significantly in the vertical direction. To be specific, at t = 1.734 msec (Figure 3.5), the piston dimension along the ground surface is about 8 meters and close to 8 meters above ground zero; however, at t = 3.965 msec (Figure 3.7), the piston size along the ground has expanded to about 12 meters whereas its height is more than 19 meters. When one refers to the air blast pressure contours (Appendix) it is apparent that this expansion of the soil piston has a significant effect upon the pressures.

3.2 Temperature Profiles

The temperature profiles at selected times after burst for the 3-meter depth calculation only are included in Figures 3.8 and 3.9. The temperatures are given in eV. units where 1 eV. is about 11,800°K. In each case, the profile defines the maximum space extent of the labeled temperature given; that is, all temperatures <u>inside</u> the profile are <u>higher</u> than the label value.

The general behavior illustrated in the figures shows a very hot region of soil/iron mixture at early times (t = 1.297 msec in Figure 3.8) located slightly above the air/soil interface. As time passes, this hot region cools somewhat, expands, and moves upward - until at t = 3.965 msec (Figure 3.9), it extends over a region of about 12 meters vertically which is centered near a height of 12 meters above ground zero. The temperature of this region is about 3 eV. (or about 30,000°K) near its outer surface and hotter on the interior. The

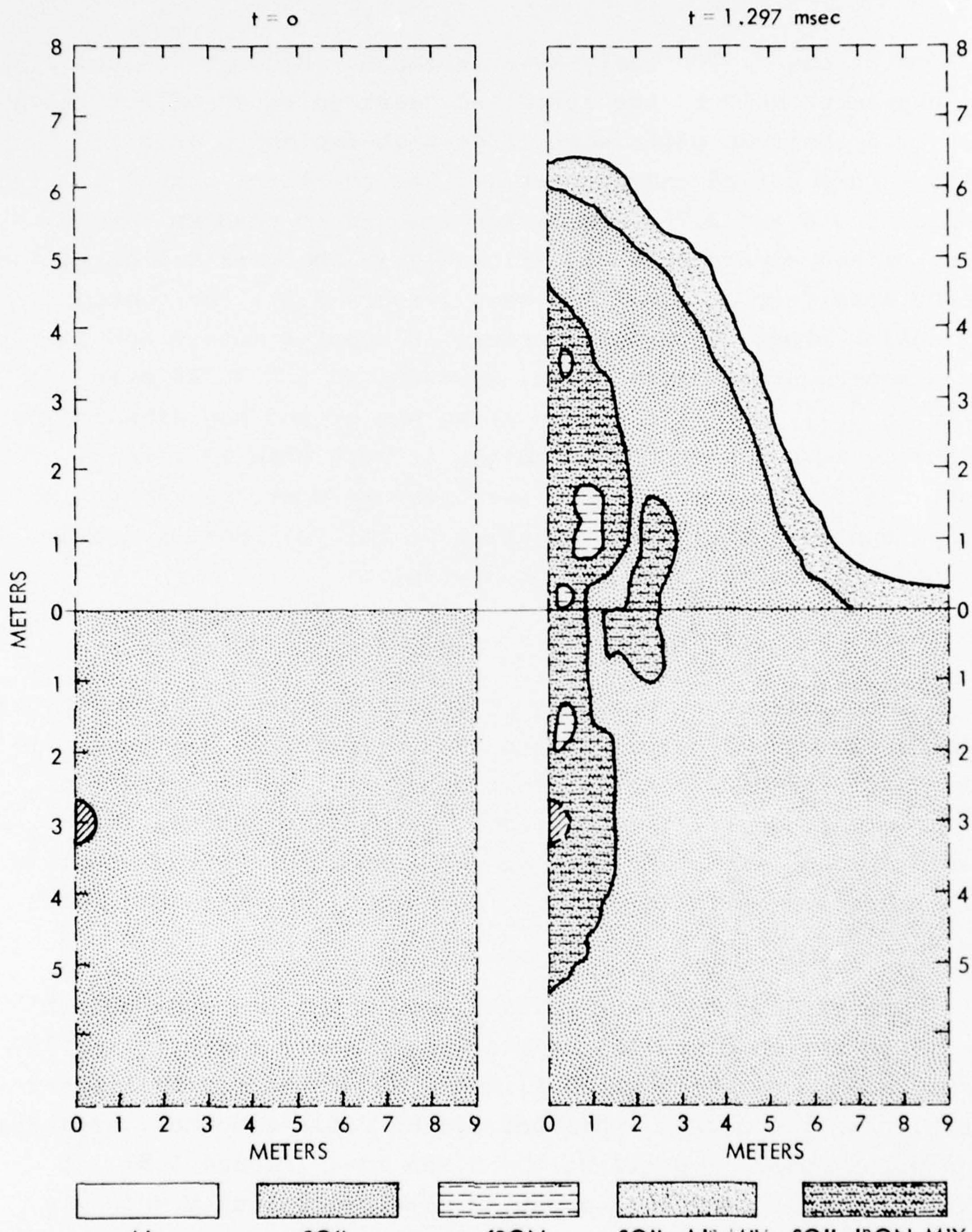

FIGURE 3.4 RAD9 CALCULATION MATERIAL PROFILES, 1-KT AT 3-METER DEPTH, t = 0 and t =1.297 MSEC

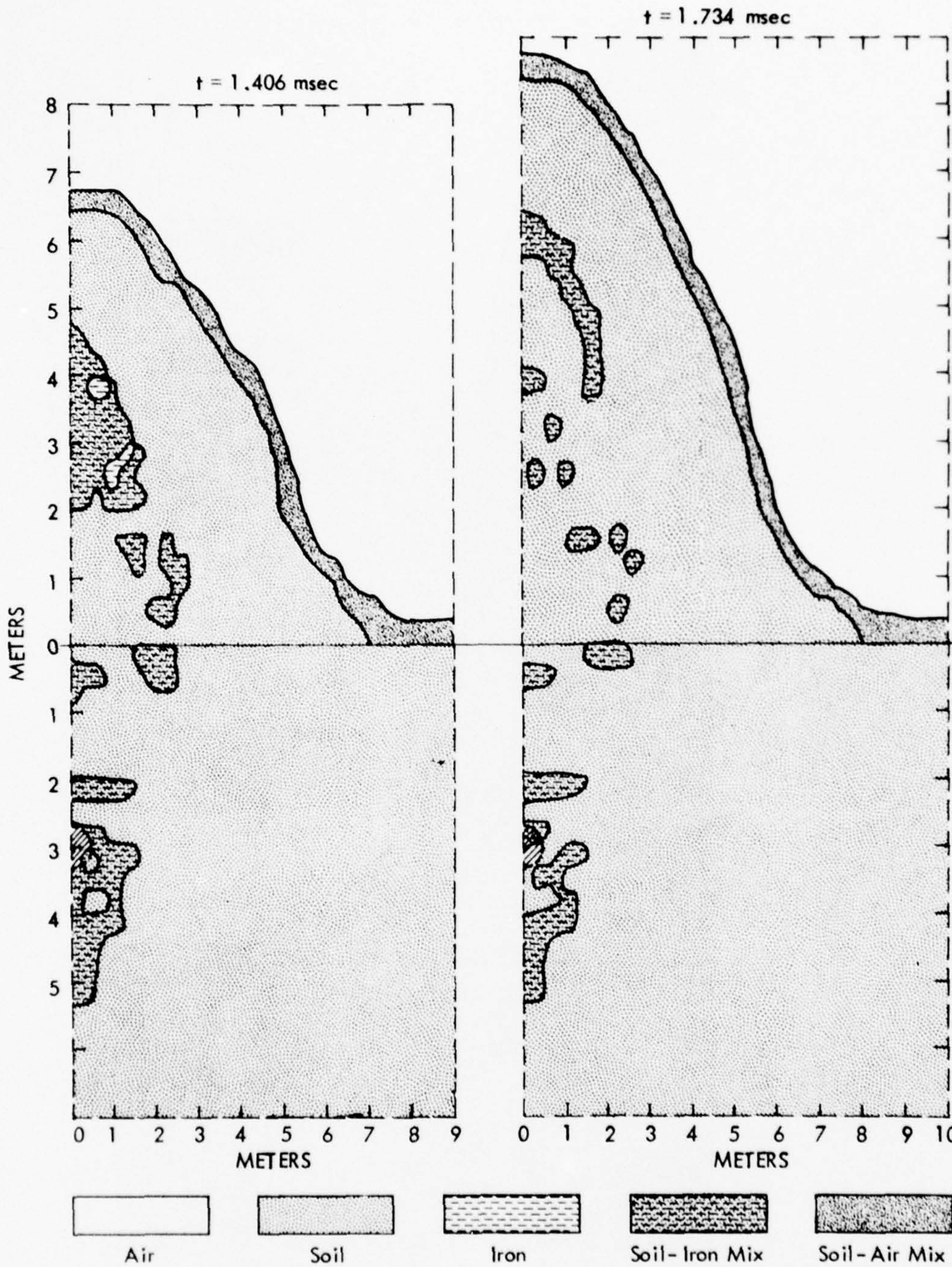

FIGURE 3.5 RAD9 CALCULATION MATERIAL PROFILES, 1-KT AT 3-METER DEPTH, t = 1.406 MSEC AND t = 1.734 MSEC

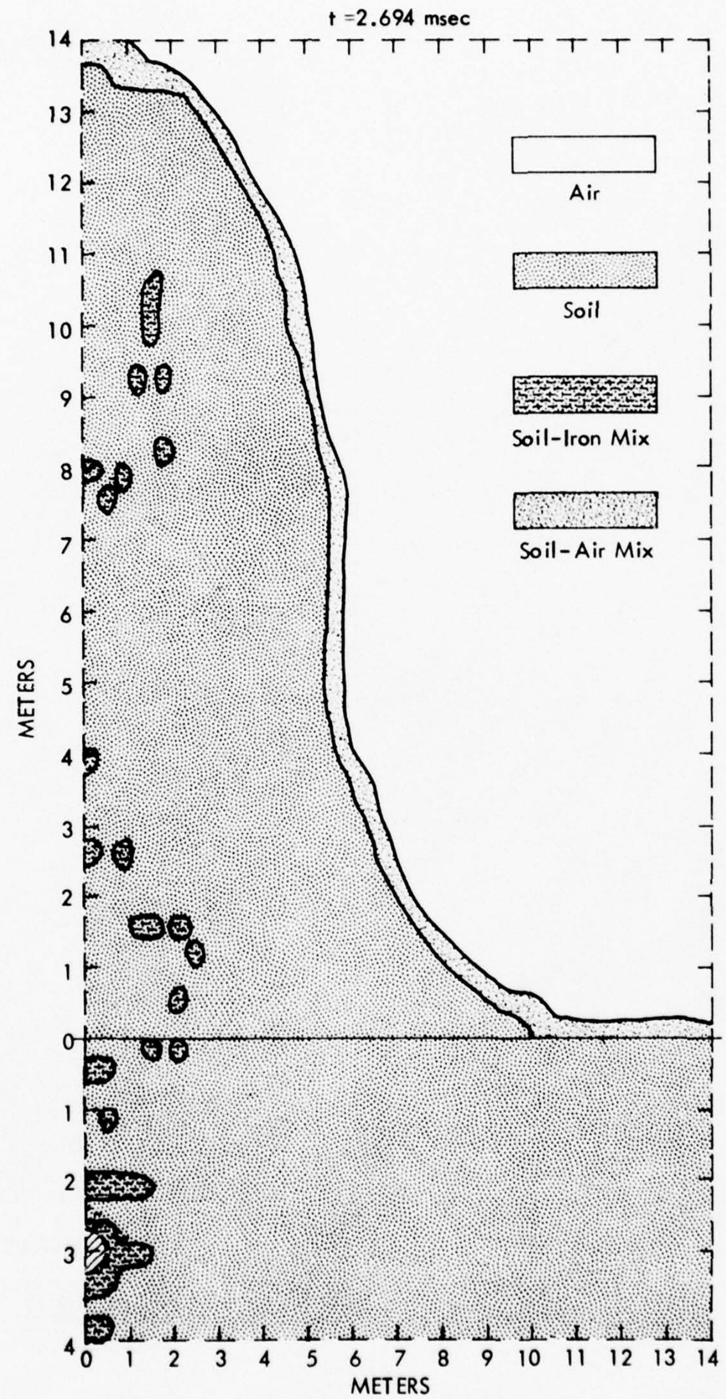

FIGURE 3.6 RAD9 CALCULATION MATERIAL PROFILE, 1-KT AT 3-METER DEPTH, t = 2.694 MSEC

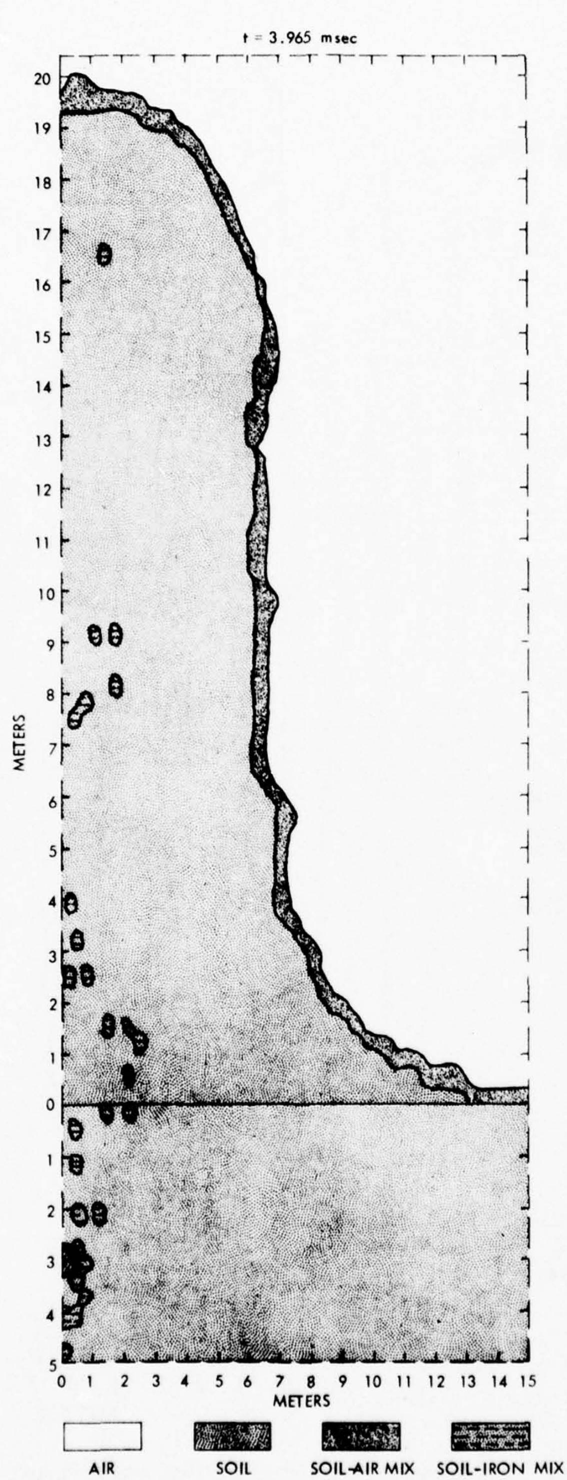

FIGURE 3.7 RAD9 CALCULATION MATERIAL PROFILES, 1-KT AT 3-METER DEPTH, t = 3.965 MSEC

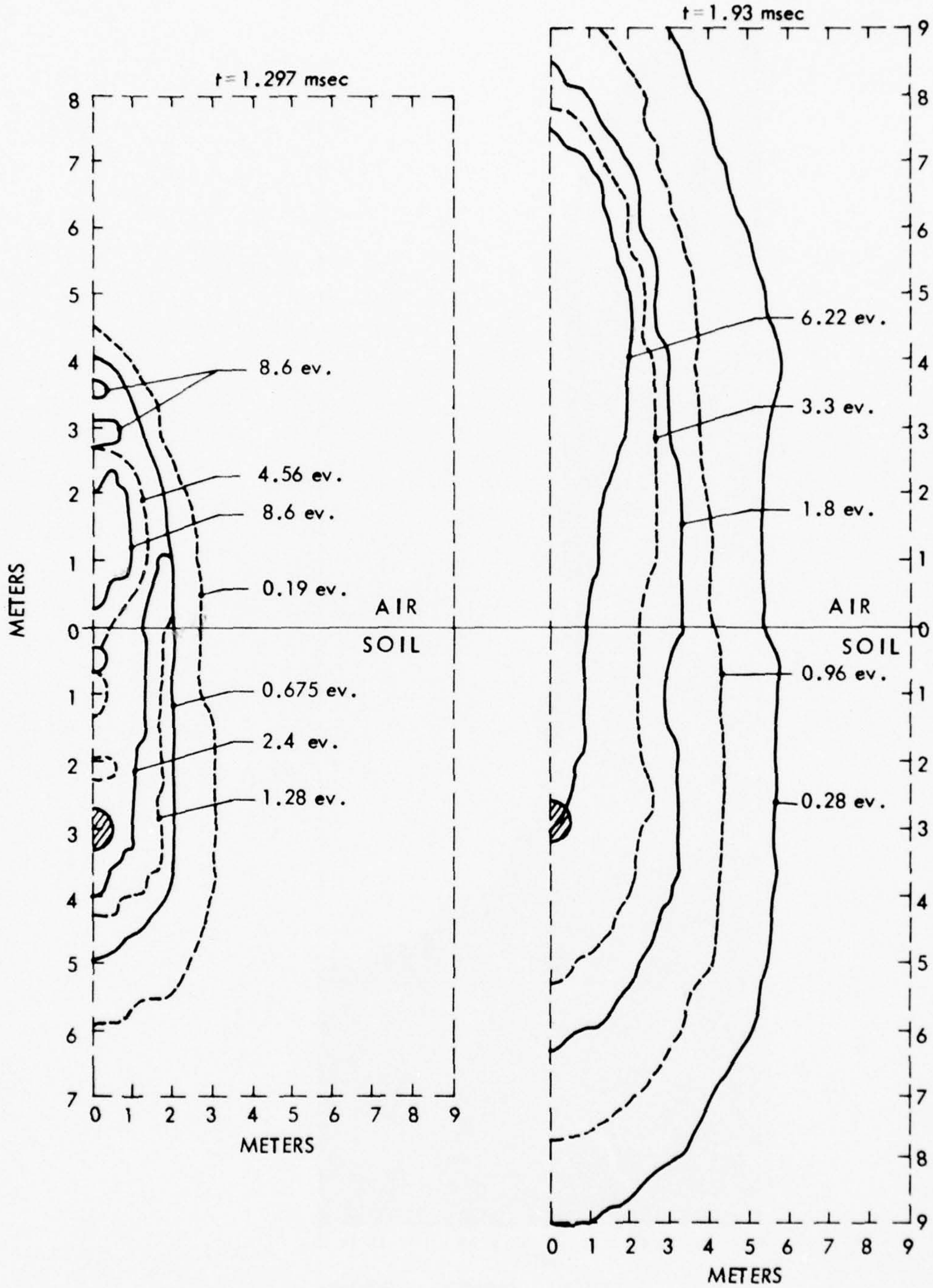

FIGURE 3.8 RAD9 CALCULATION TEMPERATURE PROFILES, 1-KT AT 3-METER DEPTH, t = 1.297 MSEC AND t = 1.93 MSEC

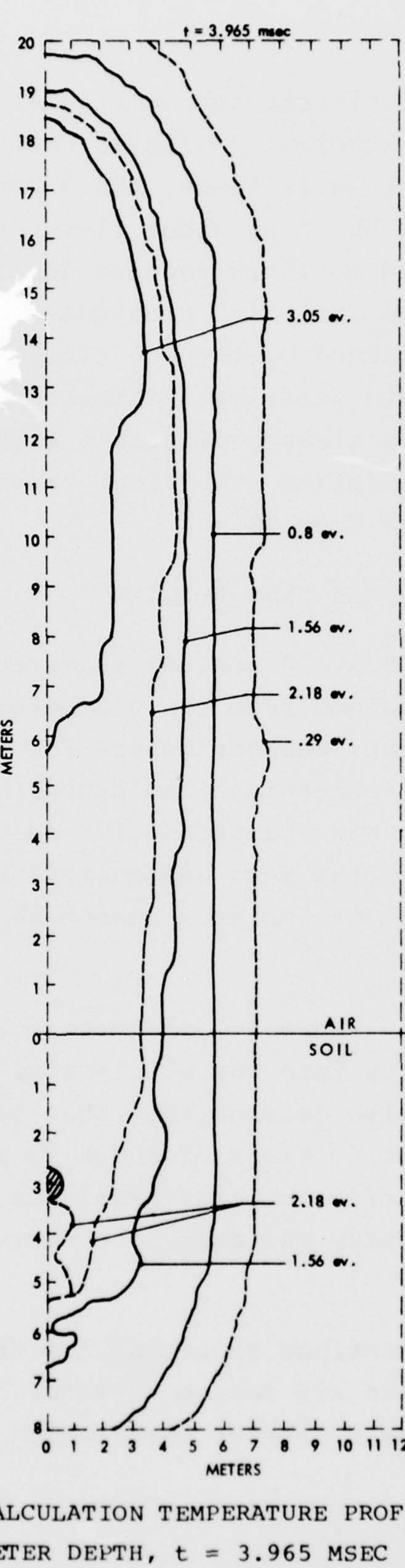

FIGURE 3.9 RAD9 CALCULATION TEMPERATURE PROFILE, 1-KT AT 3-METER DEPTH, t = 3.965 MSEC

general behavior illustrated in Figures 3.8 and 3.9 indicates that, concerning thermal radiation heating of the air and the ground surface at later times, the 3-meter depth burst acts more like an air burst at about 12-meter HOB and reduced yield. The thermal yield would be reduced due to the large amount of soil moved up and out which provides an effective shield to the radiation emitted by the hot fireball which is characterized by the temperature profiles. This shielding phenomenon adds complexity to the already-difficult problem of computing the total thermal radiation (vs. time) reaching the ground surface at various ranges from GZ.

3.3 Energy and Mass Results

Tables 3.1 and 3.2 include summaries of the energy and mass results obtained from the 0.5-meter and 3-meter depth of burst calculations, respectively. For the 0.5-meter case, the ERDA-Livermore source tape indicated that, at the time the RAD9 calculation was started (0.175 msec) the contribution from the iron to the total mass and energy is only about 0.06% and decreases with time; for this reason the iron data were omitted from Table 3.1.

Reference to Table 3.1 indicates that the fraction of the total energy going into the air is increasing with time. However, it is also evident that this calculation would have to be carried out to times of about 10 msec to accurately determine the air/soil energy partition. The table listings indicate that energy and mass is conserved very well during the calculation.

Table 3.2 listings show that the fraction of total energy partitioned to the air for the 3-meter buried charge is much less than for the 0.5-meter case, which is as expected. Also,

TABLE 3.1

SUMMARY OF ENERGY AND MASS RESULTS FROM 0.5-METER DOB KAMAN SCIENCES RAD9 CALCULATION

MATERIAL	INT. E (jerks)+	KIN. E (jerks)	TOTAL E (jerks)	TOTAL MASS (gms)	TIME (msec)
Soil Air Totals	1775 702 2478	1831 341 2172	3602 1043 4650	1.579(+10)* 1.99(+7) 1.581(+10)	0.175
Soil Air Totals	1773 722 2495	1815 340 2155	3588 1062 4650	1.579(+10) 1.99(+7) 1.581(+10)	0.180
Soil Air Totals	1762 764 2526	1776 348 2124	3538 1112 4650	1.579(+10) 1.99(+7) 1.581(+10)	0.193
Soil Air Totals	1722 873 2594	1667 389 2056	3389 1262 4650	1.579(+10) 1.99(+7) 1.581(+10)	0.248
Soil Air Totals	1676 992 2668	1541 441 1982	3216 1434 4650	1.579(+10) 1.99(+7) 1.581(+10)	0.342
Soil Air Totals	1632 1106 2738	1434 478 1912	3066 1583 4650	1.579(+10) 1.98(+7) 1.581(+10)	0.469
Soil Air Totals	1631 1108 2739	1432 478 1911	3064 1586 4650	1.579(+10) 1.98(+7) 1.581(+10)	0.472

+jerk = 10^{16} ergs

*1.579(+10) = 1.579×10^{10}

TABLE 3.2

SUMMARY OF ENERGY AND MASS RESULTS FROM 3-METER DOB
KAMAN SCIENCES RAD9 CALCULATION

MATERIAL	INT. E (jerks)+	KIN. E (jerks)	TOTAL E (jerks)	TOTAL MASS (gms)	TIME (msec)
Iron	14.3	0.68	15.0	1.76(+4)*	1.297
Soil	2661	1913	4575	2.535(+10)	
Air	16.0	2.79	18.8	2.32(+7)	
Totals	2692	1917	4608	2.537(+10)	
Iron	4.56	0.82	5.39	2.77(+4)	1.406
Soil	2662	1923	4585	2.535(+10)	
Air	14.8	2.89	17.68	2.32(+7)	
Totals	2681	1927	4608	2.537(+10)	
Iron	2.06	0.48	2.54	2.55(+4)	1.734
Soil	2651	1931	4582	2.535(+10)	
Air	18.67	3.94	22.6	2.32(+7)	
Totals	2671	1936	4607	2.537(+10)	
Iron	1.44	0.38	1.82	2.44(+4)	1.928
Soil	2649	1930	4579	2.535(+10)	
Air	21.73	4.87	26.60	2.32(+7)	
Totals	2672	1935	4607	2.537(+10)	
Iron	1.00	0.28	1.28	2.31(+4)	2.164
Soil	2648	1925	4573	2.535(+10)	
Air	25.97	6.24	32.2	2.32(+7)	
Totals	2675	1932	4607	2.537(+10)	
Iron	0.63	0.21	0.84	2.01(+4)	2.694
Soil	2651	1909	4559	2.535(+10)	
Air	36.87	9.65	46.52	2.32(+7)	
Totals	2688	1919	4607	2.537(+10)	
Iron	0.33	0.13	0.46	1.53(+4)	3.345
Soil	2669	1869	4538	2.5346(+10)	
Air	49.46	13.22	62.68	2.32(+7)	
Totals	2719	1883	4601	2.537(+10)	
Iron	0.23	0.08	0.31	1.44(+4)	3.965
Soil	2683	1813	4496	2.5326(+10)	
Air	61.1	16.22	77.3	2.32(+7)	
Totals	2745	1829	4574	2.535(+10)	
Iron	0.233	0.078	0.31	1.44(+4)	3.981
Soil	2684	1811	4495	2.5325(+10)	
Air	61.4	16.30	77.72	2.32(+7)	
Totals	2746	1827	4573	2.535(+10)	

+jerk = 10^{16} ergs

*1.76(+4) = 1.76×10^4

it is evident that, at early times, the contribution of the energy from the iron to the total energy is significant; as time proceeds, this contribution rapidly decreases. It is estimated that this calculation would need to be carried out to times near 100 msec to obtain accurate data regarding air/soil energy partition. Using the data available from these calculations, an "educated guess" would say that the fraction of energy appearing as air blast for the 3-meter case is less than one would predict using the standard effective yield concept. This conclusion should be verified by carrying out the calculations to the required later times.

Carrying out the KSC RAD9 calculations of the 0.5-meter and 3-meter cases to later times would not require excessive computer costs. The results reported here were obtained using a CDC 7600 Computer with the following run times:

(a) 0.5-meter case - 19 min.

(b) 3-meter case - 16 min.

3.4 Contour Plots of the Results

Plots of space contours of pressure, density, velocity vectors and internal energy are presented in an Appendix to this report. The plots are given for:

1. 0.5-meter DOB (1-KT); t = 0.472 msec
2. 3-meter DOB (1-KT); t = 3.981 msec.

The Z- and R-axes are labeled in centimeters; for the 0.5-meter case the air/soil interface is at Z = 1000 centimeters and for the 3-meter case the air/soil interface is at Z = 1600 centimeters.

For the 0.5-meter case, some pressure vs. radius plots are presented, corresponding to selected values of constant Z.

4.0 SUGGESTED FURTHER WORK

It is suggested that the following work be done with the KSC RAD9 Code:

1. Continue the KSC RAD9 calculations of the 1 KT-3 meter case to about 200 msec and the 1 KT-0.5 meter case to about 20 msec to determine the yield fraction contributing to air blast in each case.

2. Using the results obtained from 1. above, compare these results with the AFWL HULL Code calculations (using the Tillotson Equation of State) for the same cases.

3. Using the KSC RAD9 Code, complete the following sensitivity studies:

   (a) Determine the effect of changing (within sensible limits) the linear and/or quadratic terms in the artificial viscosity used in the problem. Most of the codes used for these calculations incorporate the artificial viscosity formalism.

   (b) Determine the effect of zone size near the source and at the shock front. There is some evidence that even the "shock-following" routine used by AFWL is not adequate to define the peak overpressure accurately at low (less than 20 psi) overpressures. Kaman Sciences is developing a "packaging" routine which will help to define these peak overpressures without the use of excessive computer time.

(c) Determine the parameters which cause the most severe radiation leakage in the calculations considered. One candidate is the value chosen for the "flux-limiter" variable.

(d) Determine the effect of allowing materials to "mix" inside the Euler cells, particularly when high opacity materials are adjacent to low opacity materials. This situation could lead to excess leakage of radiation, significantly influencing the results.

APPENDIX

PLOTS OF THE RAD9 CODE RESULTS

This appendix includes Figures A.1 through A.40. The subjects covered can be summarized as:

1. 1-KT; 0.5-meter DOB; t = 0.472 msec

   (a) Figures A.1 through A.7: Pressure Contours (Z-R space)

   (b) Figures A.8 through A.10: Pressure vs. R Profiles

   (c) Figures A.11 through A.17: Density Contours (Z-R space)

   (d) Figure A.18: Velocity Vectors (Z-R space)

   (e) Figures A.19 through A.22: Internal Energy Contours (Z-R space).

2. 1-KT; 3-meter DOB; t = 3.981 msec

   (a) Figures A.23 through A.29: Pressure Contours (Z-R space)

   (b) Figures A.30 through A.36: Density Contours (Z-R space)

   (c) Figure A.37: Velocity Vectors (Z-R space)

   (d) Figures A.38 through A.40: Internal Energy (Z-R space).

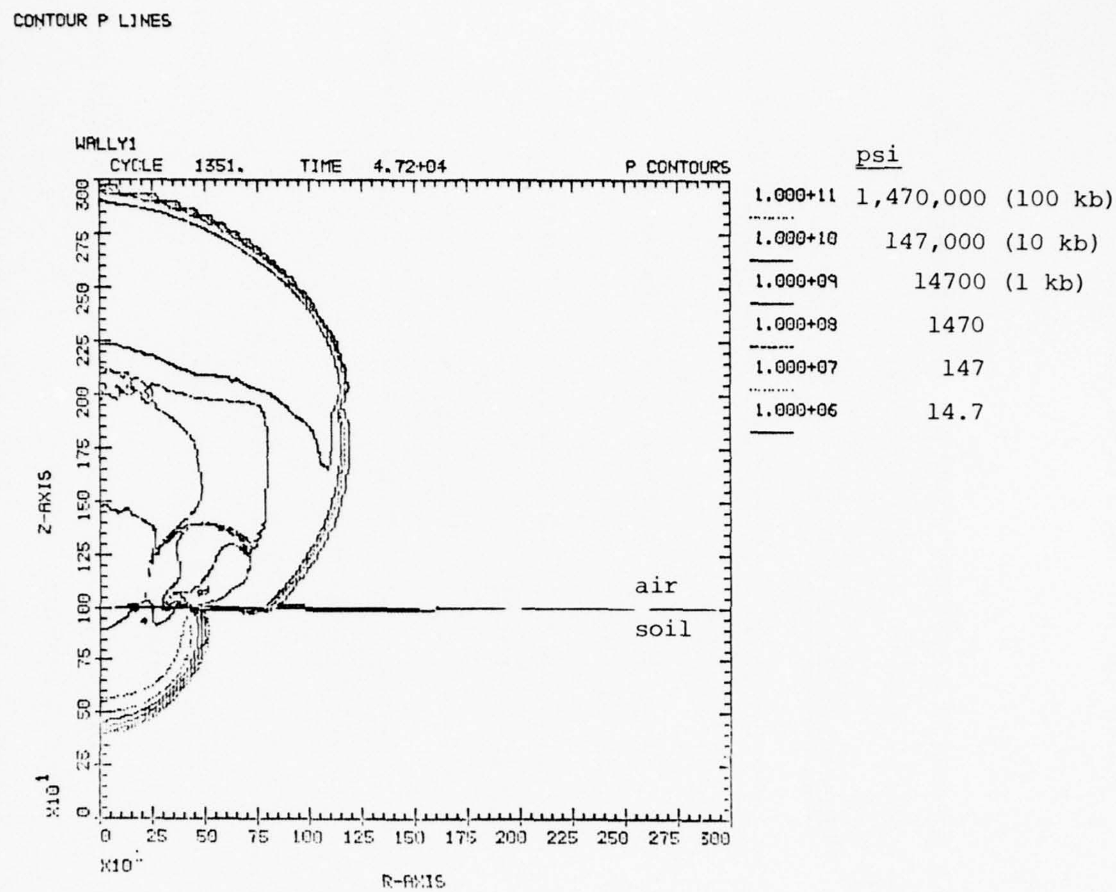

FIGURE A.1 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; CONTOURS OF CONSTANT PRESSURE

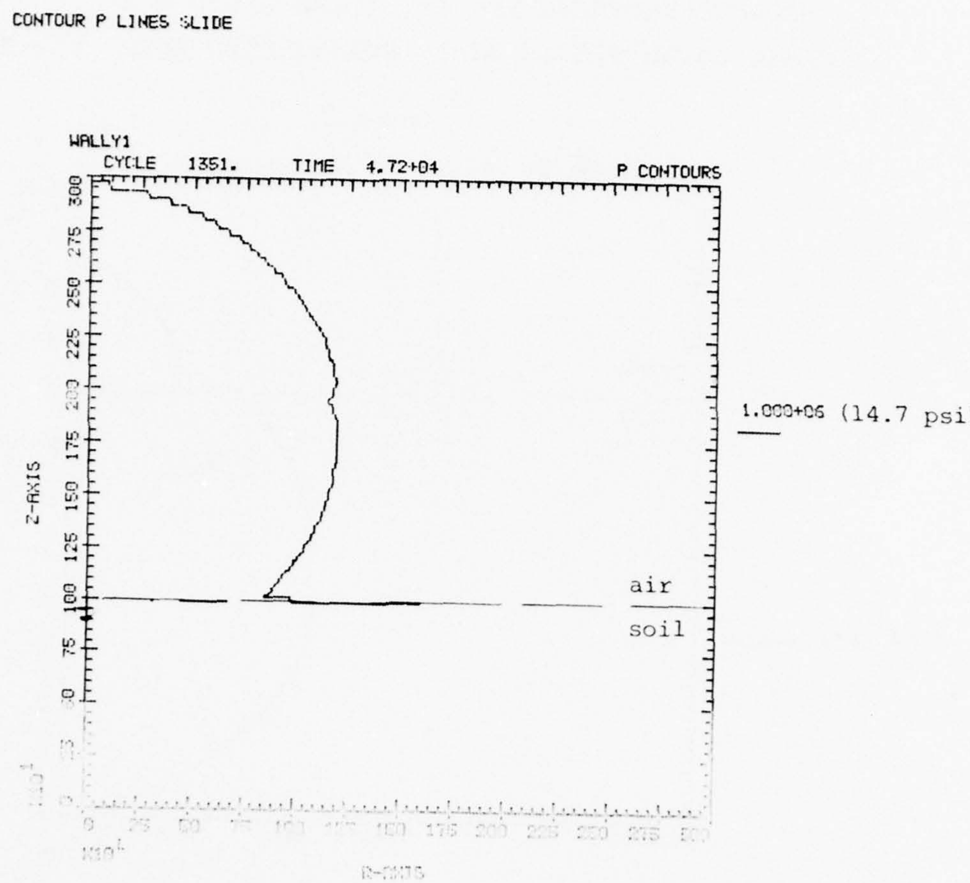

FIGURE A.2 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; 14.7 PSI PRESSURE CONTOUR

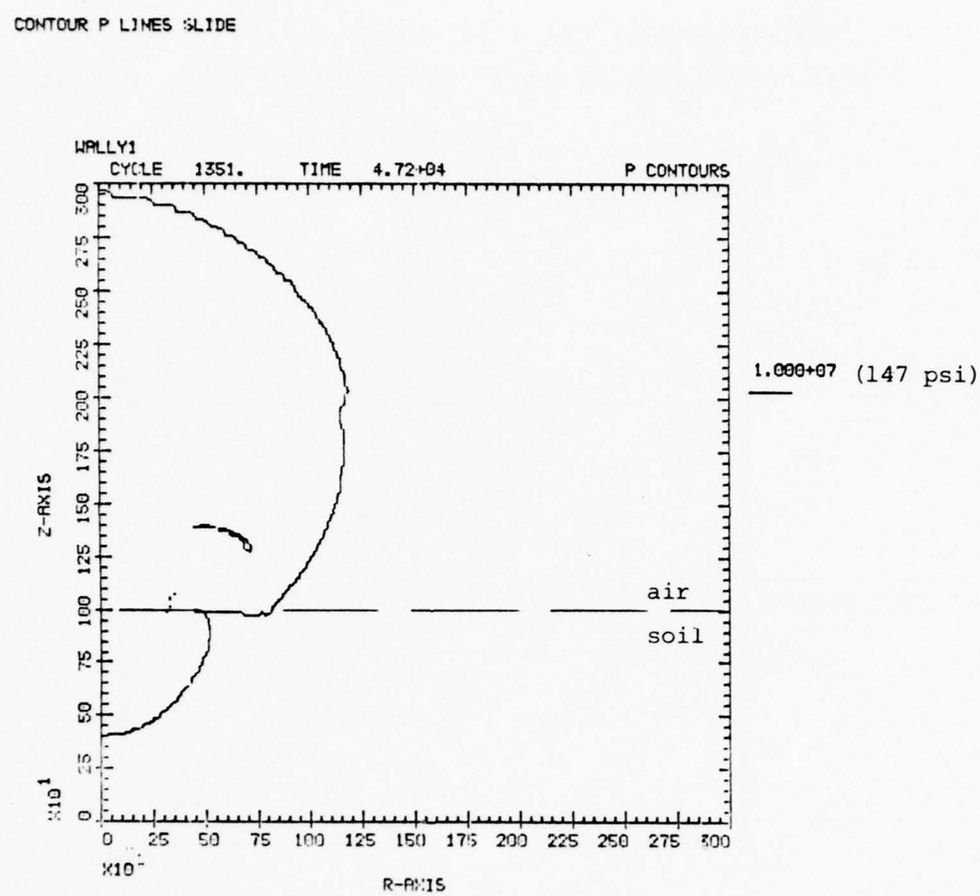

FIGURE A.3 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; 147 PSI PRESSURE CONTOUR

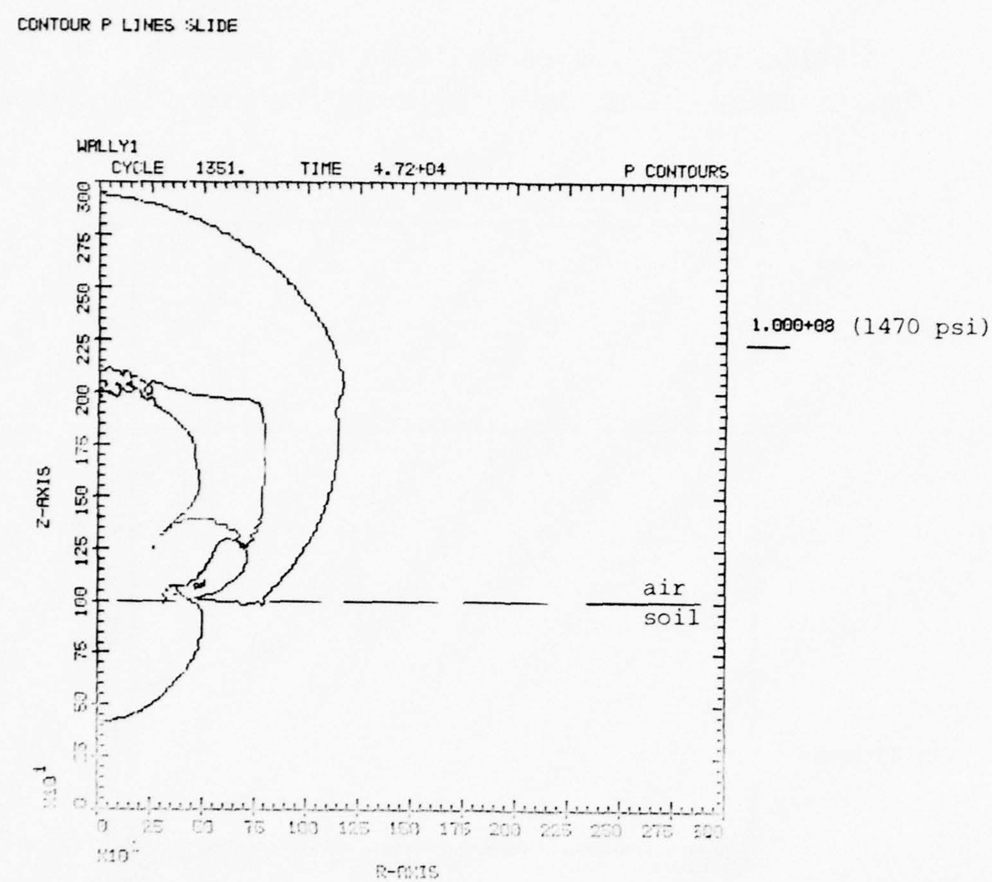

FIGURE A.4 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; 1470 PSI PRESSURE CONTOUR

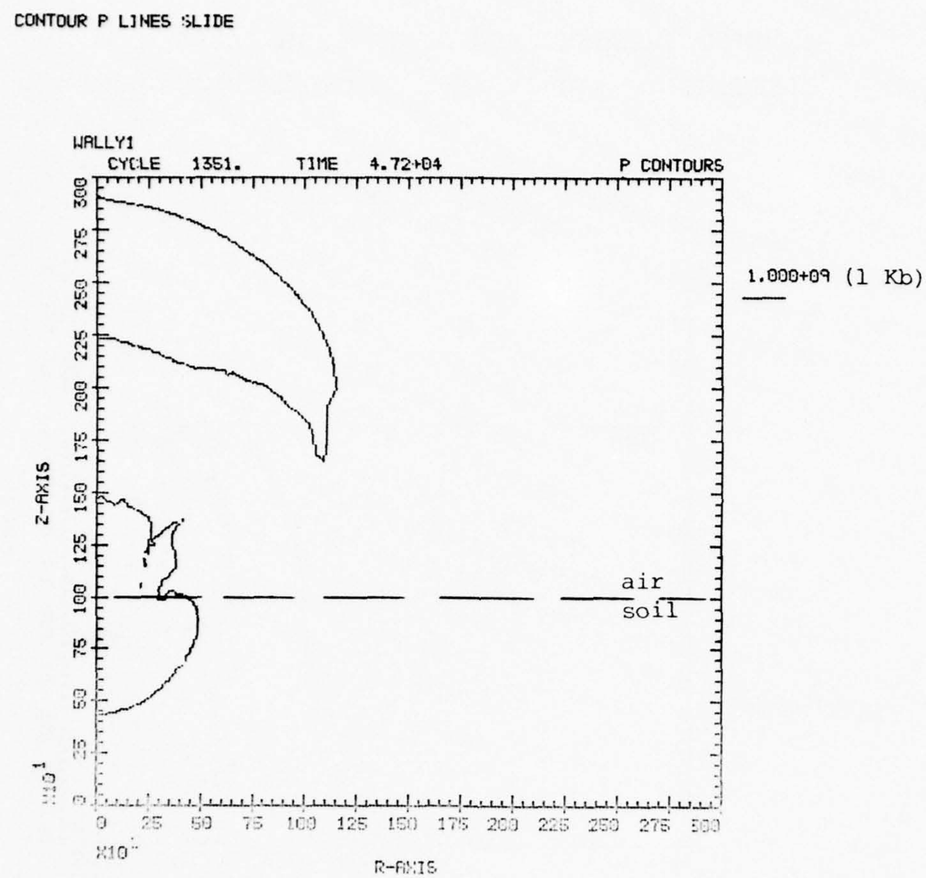

FIGURE A.5 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; 14700 PSI (1 KB) PRESSURE CONTOUR

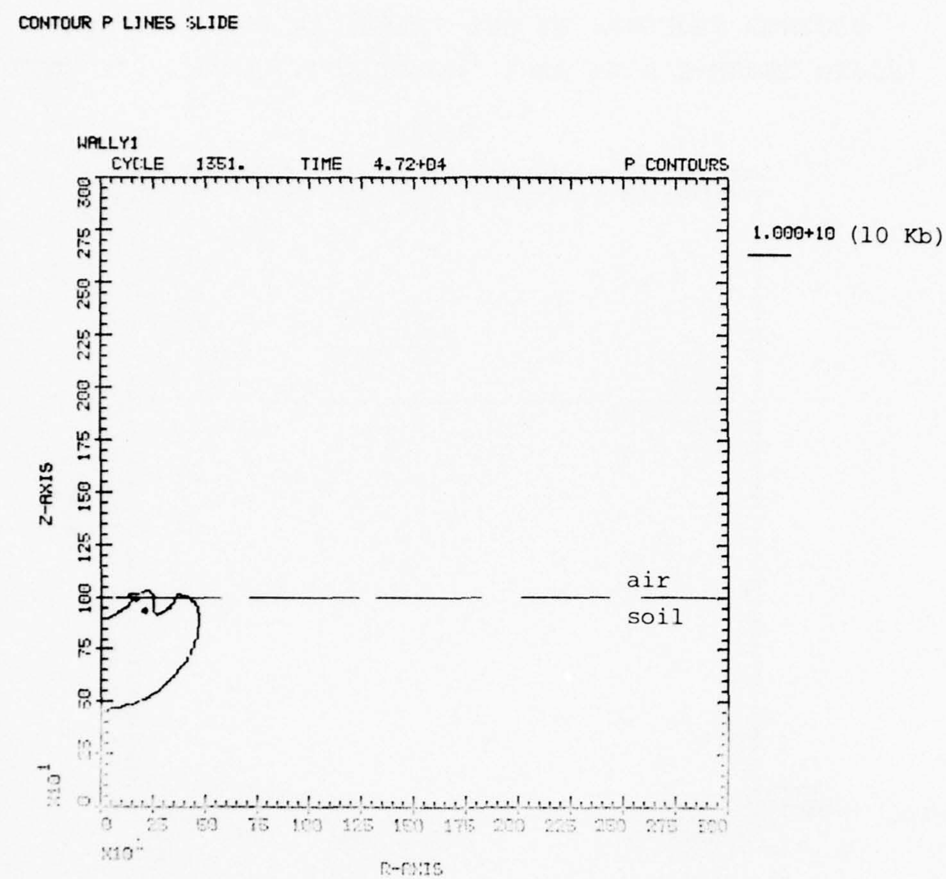

FIGURE A.6 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH,
t = 0.472 MSEC; 10 KB PRESSURE CONTOUR

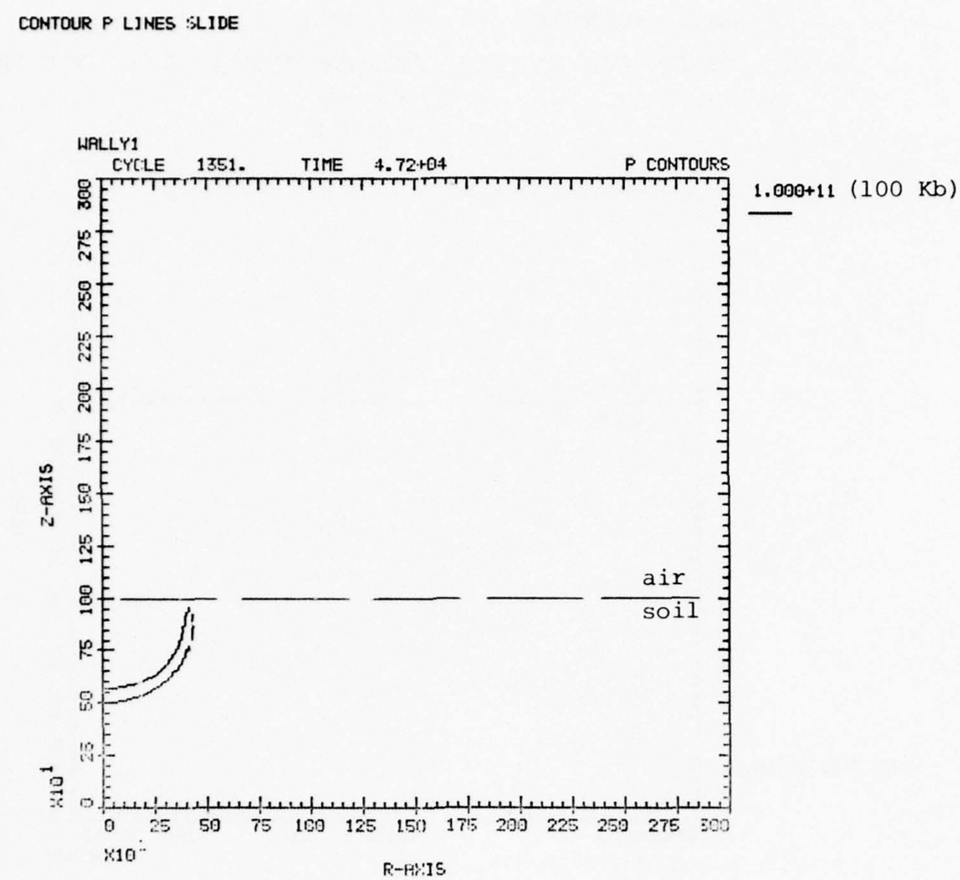

FIGURE A.7 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; 100 KB PRESSURE CONTOUR

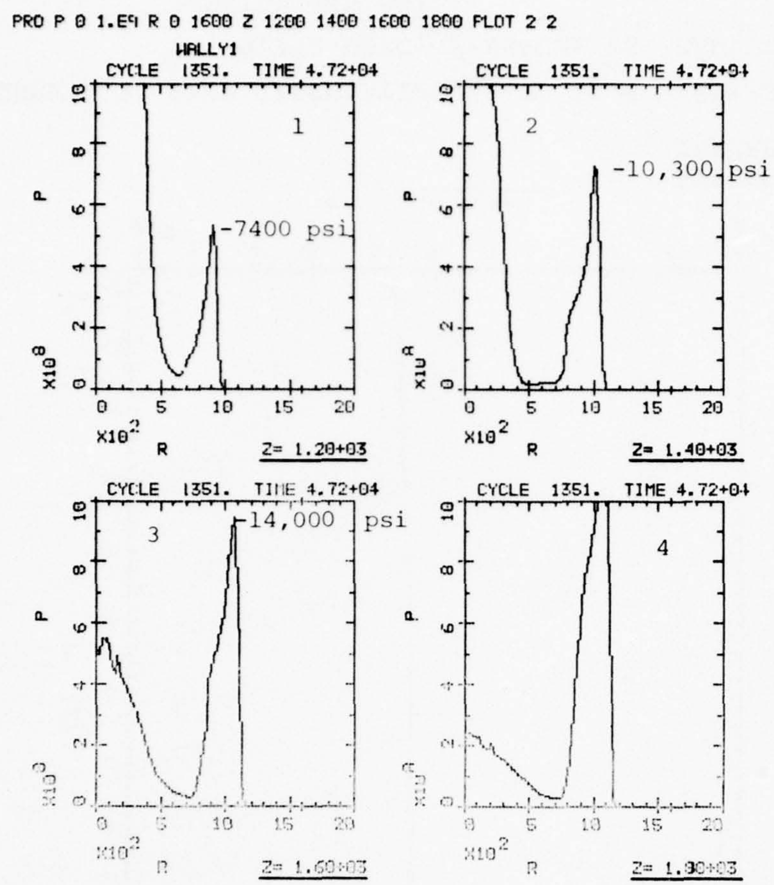

FIGURE A.8 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; PRESSURE VS. RADIUS PROFILES (IN AIR)

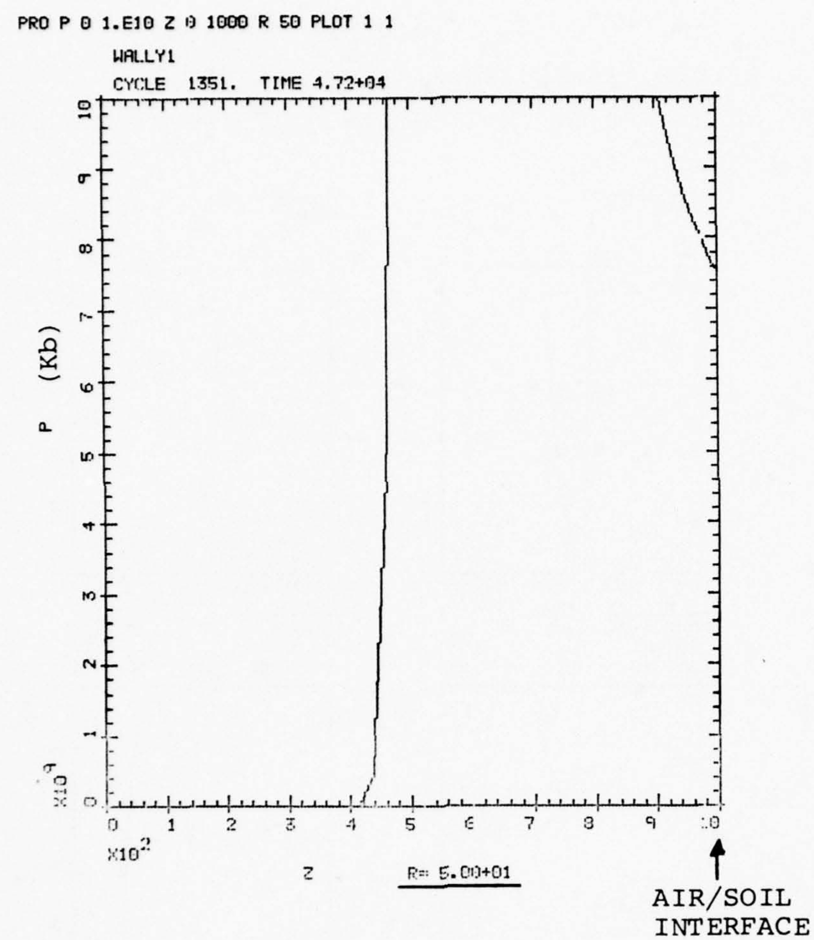

FIGURE A.9 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; PRESSURE VS. RADIUS PROFILE (IN SOIL)

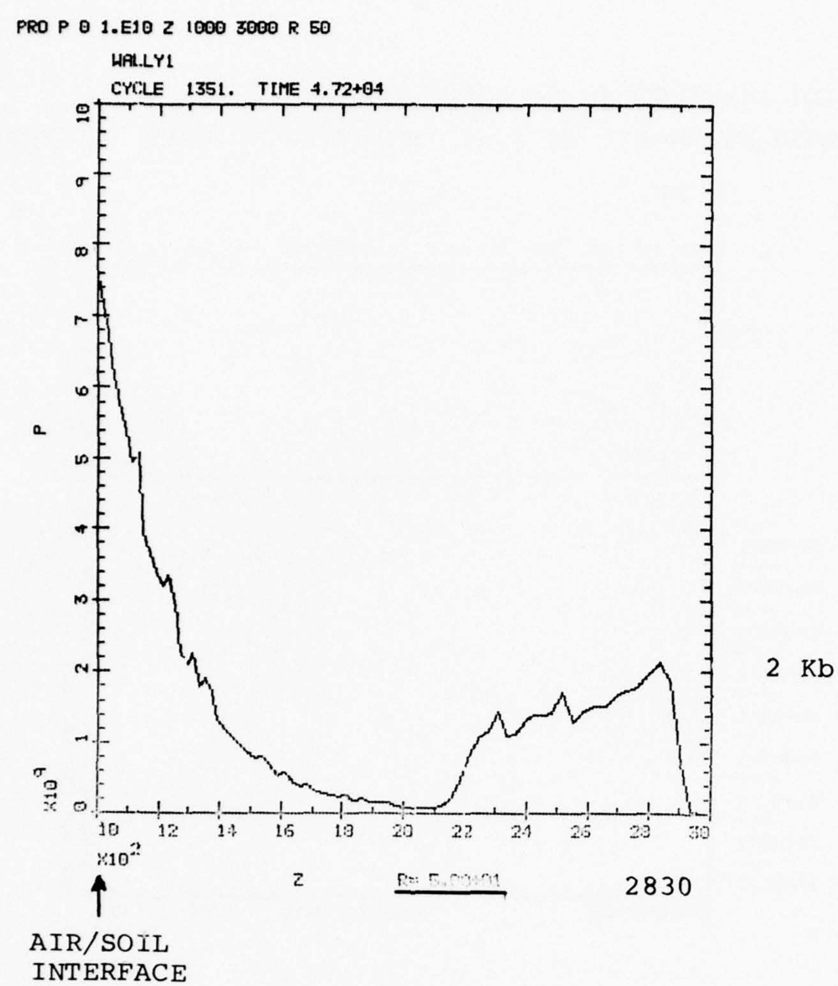

FIGURE A.10 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; PRESSURE VS. RADIUS PROFILE (IN AIR)

CONTOUR DEN LINES

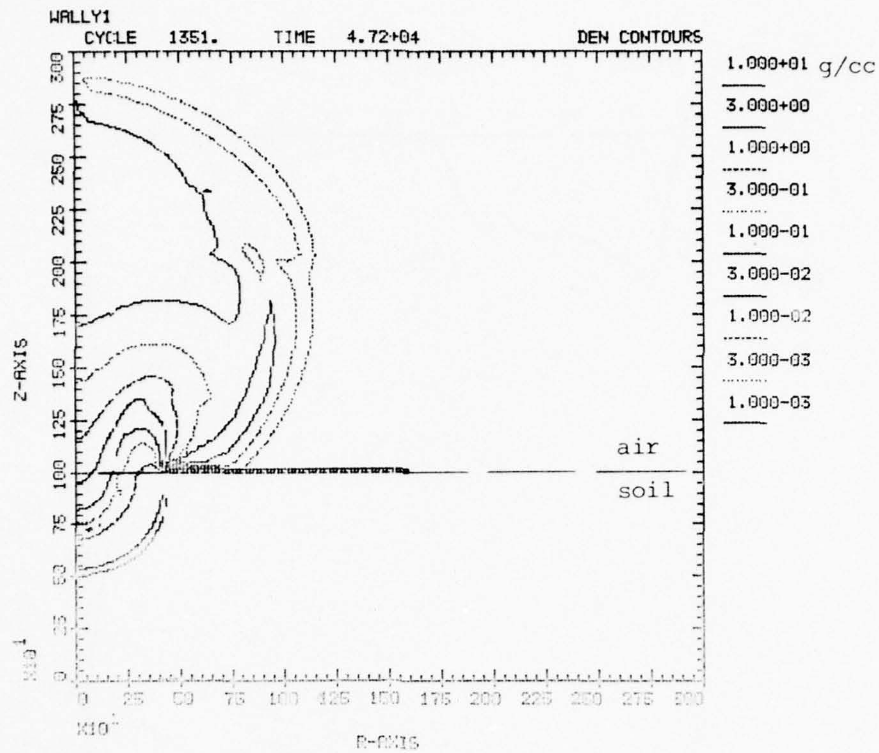

FIGURE A.11 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; CONTOURS OF CONSTANT DENSITY

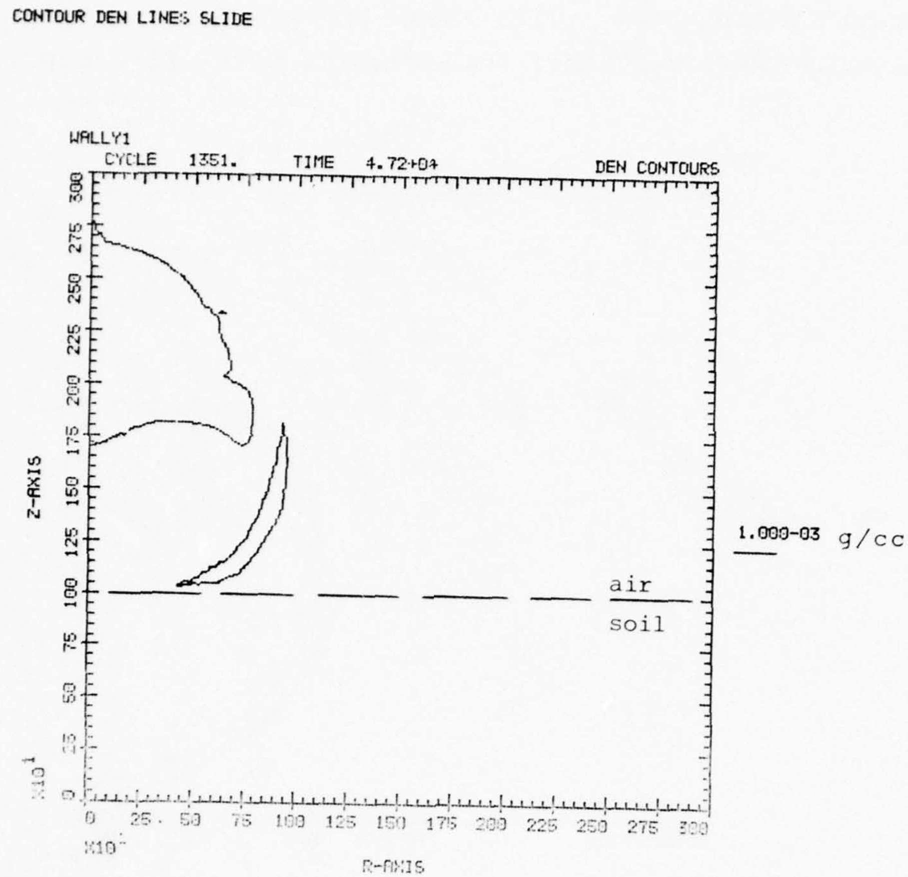

FIGURE A.12 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, $t = 0.472$ MSEC; 1×10^{-3} g/cc DENSITY CONTOUR

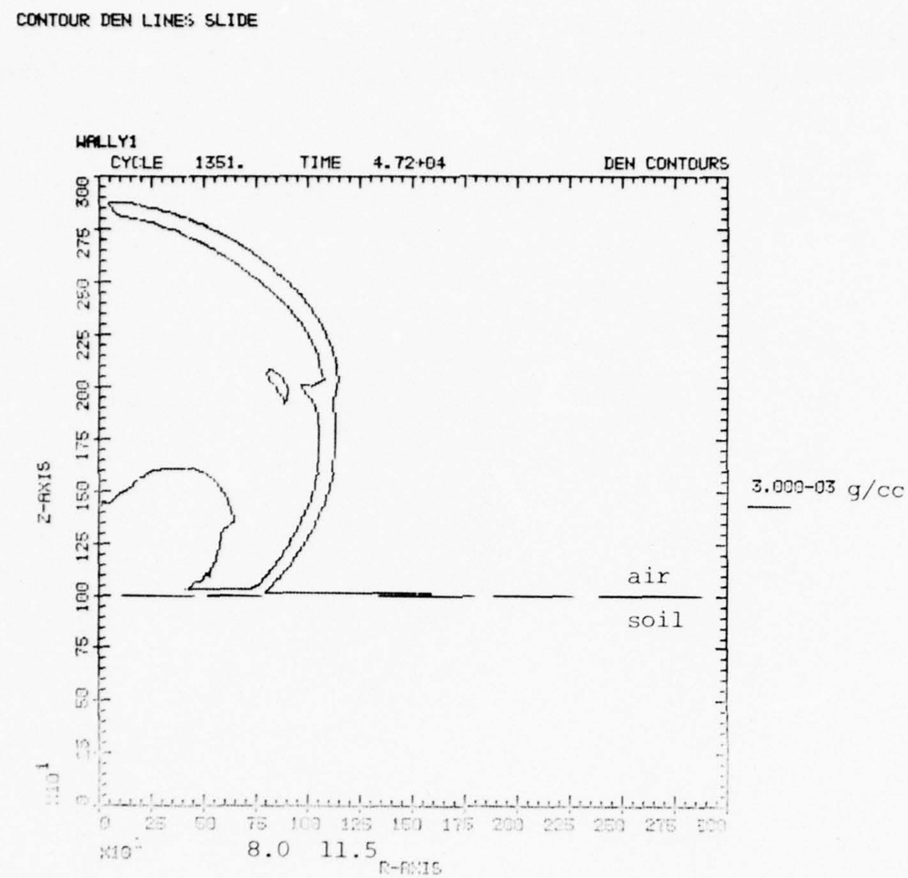

FIGURE A.13 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, $t = 0.472$ MSEC; 3×10^{-3} g/cc DENSITY CONTOUR

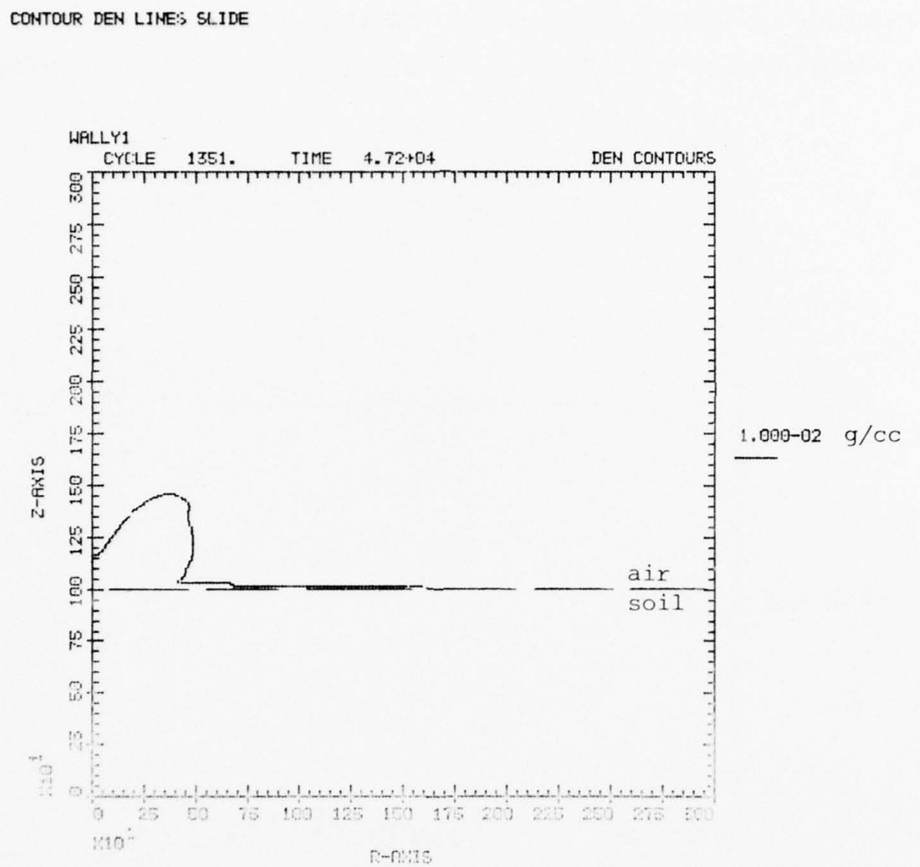

FIGURE A.14 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; 1×10^{-2} g/cc DENSITY CONTOUR

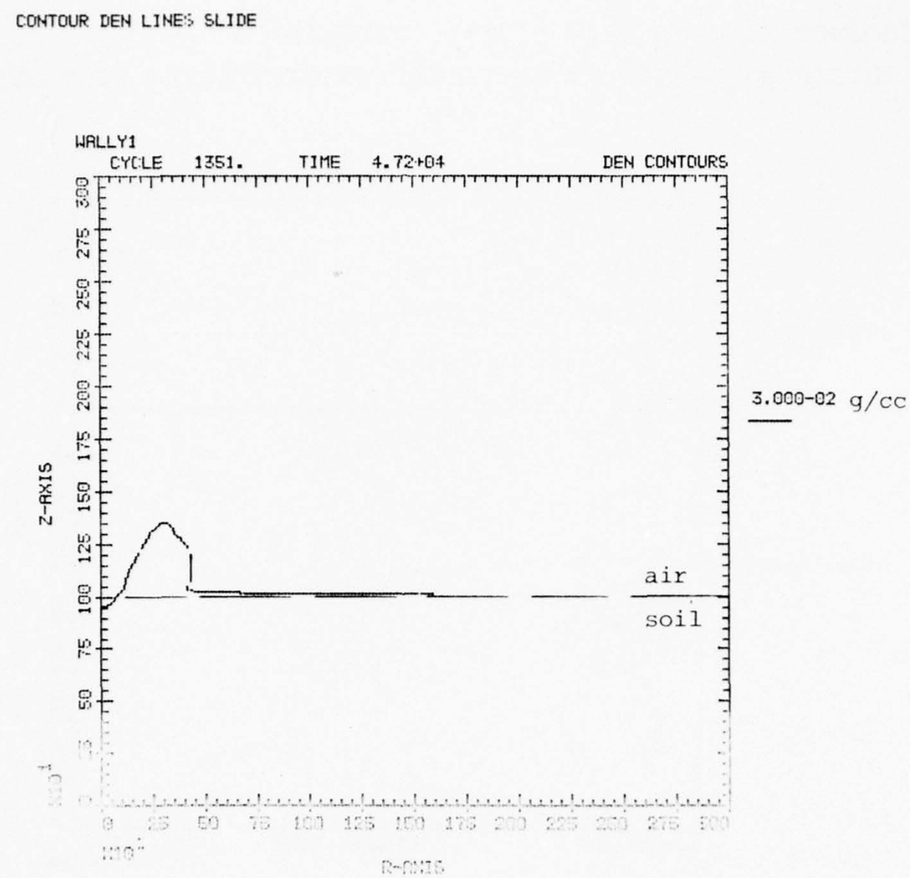

FIGURE A.15 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, $t = 0.472$ MSEC; 3×10^{-2} g/cc DENSITY CONTOUR

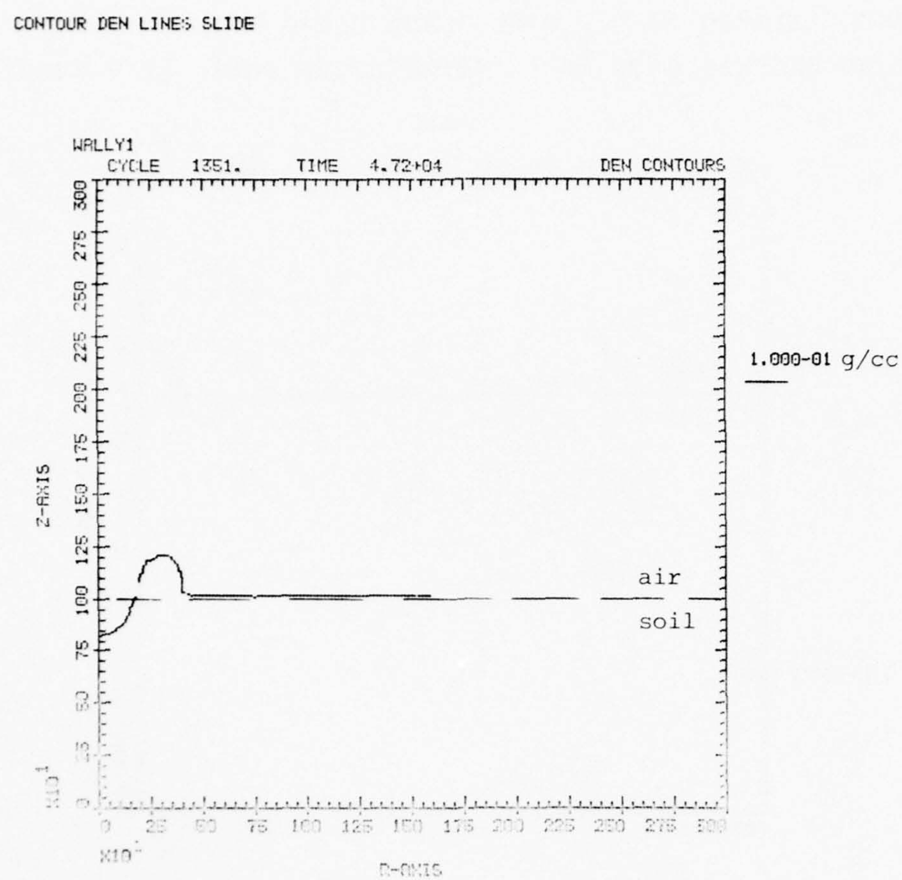

FIGURE A.16 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, $t = 0.472$ MSEC; 1×10^{-1} g/cc DENSITY CONTOUR

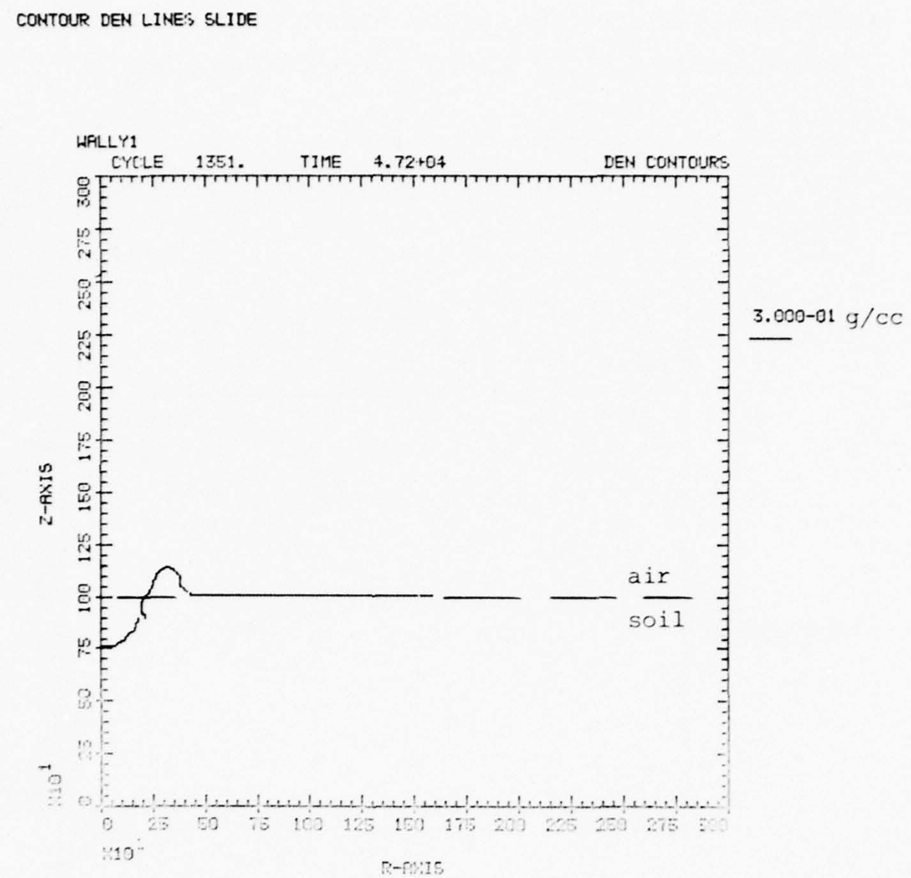

FIGURE A.17 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, $t = 0.472$ MSEC; 3×10^{-1} g/cc DENSITY CONTOUR

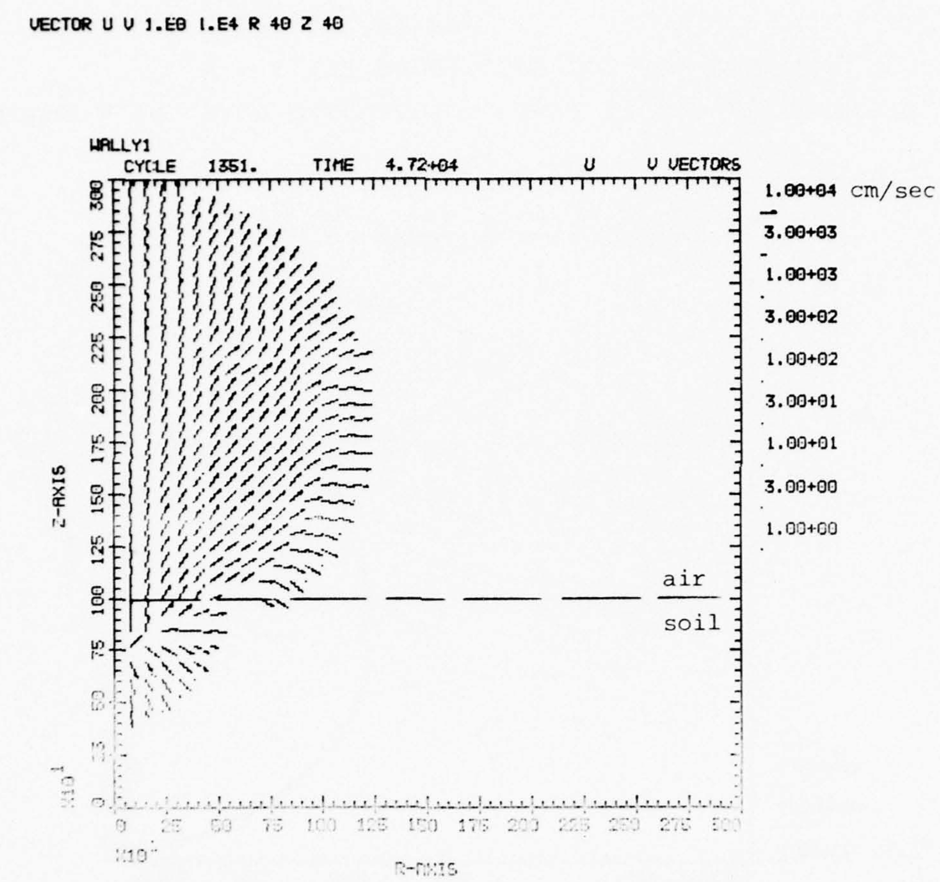

FIGURE A.18 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; PARTICLE VELOCITY VECTORS (CM/SEC)

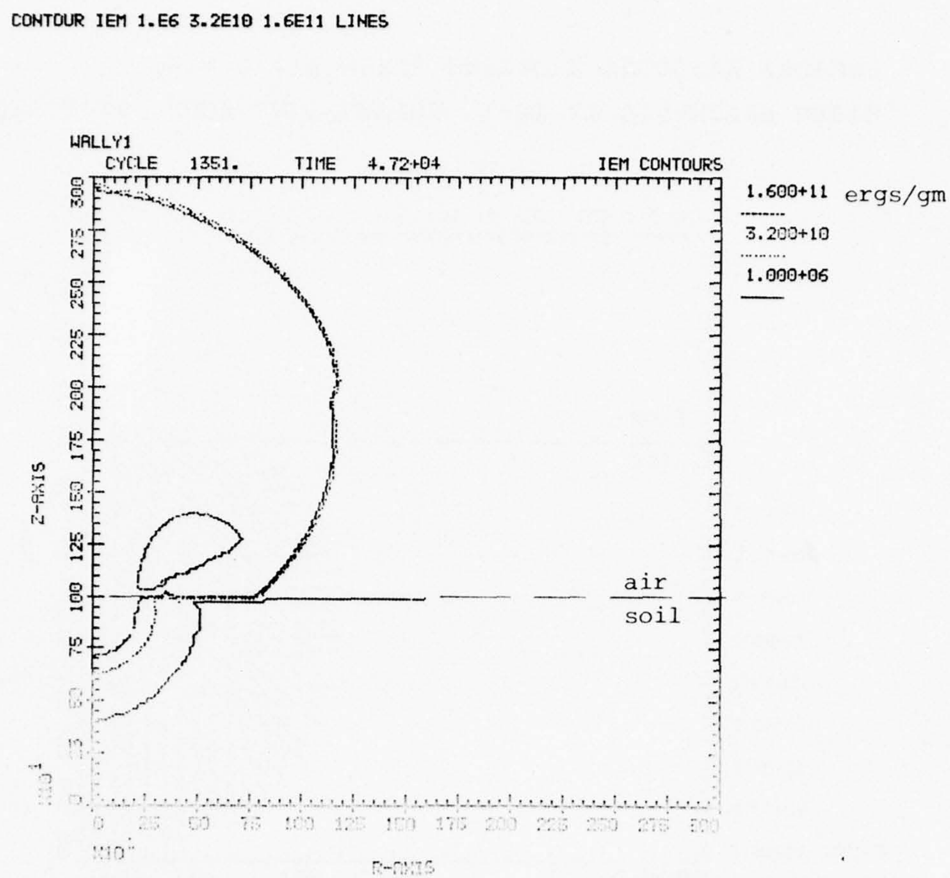

FIGURE A.19 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; CONTOURS OF CONSTANT INTERNAL ENERGY

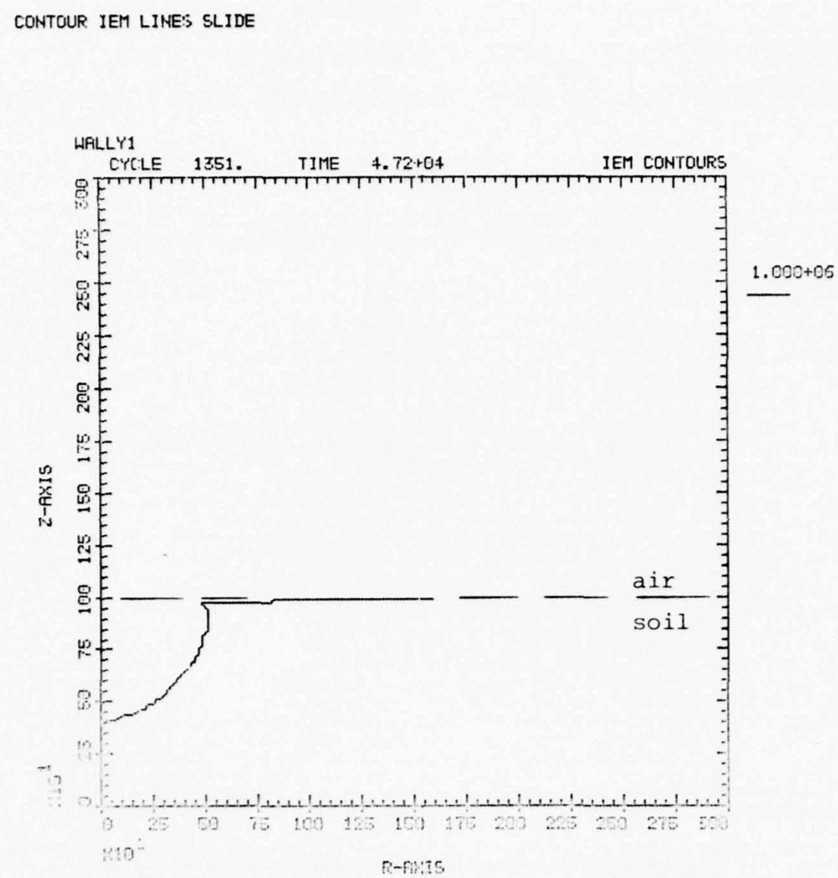

FIGURE A.20 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; 1×10^6 ERGS/GM INTERNAL ENERGY CONTOUR

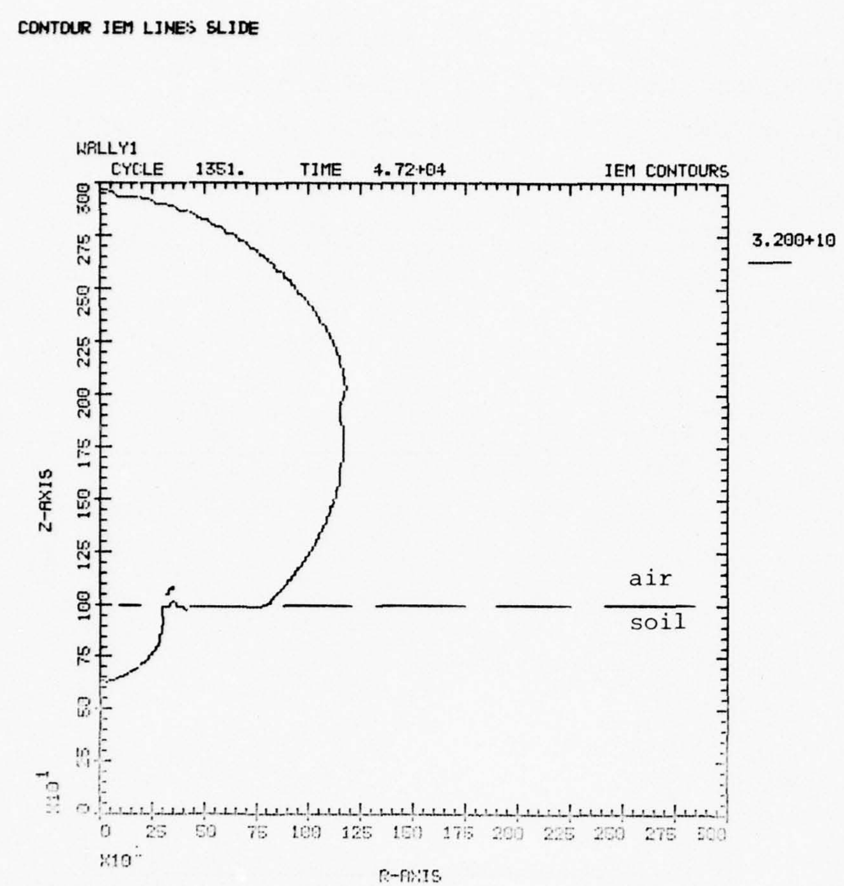

FIGURE A.21 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; 3.2×10^{10} ERGS/GM INTERNAL ENERGY CONTOUR

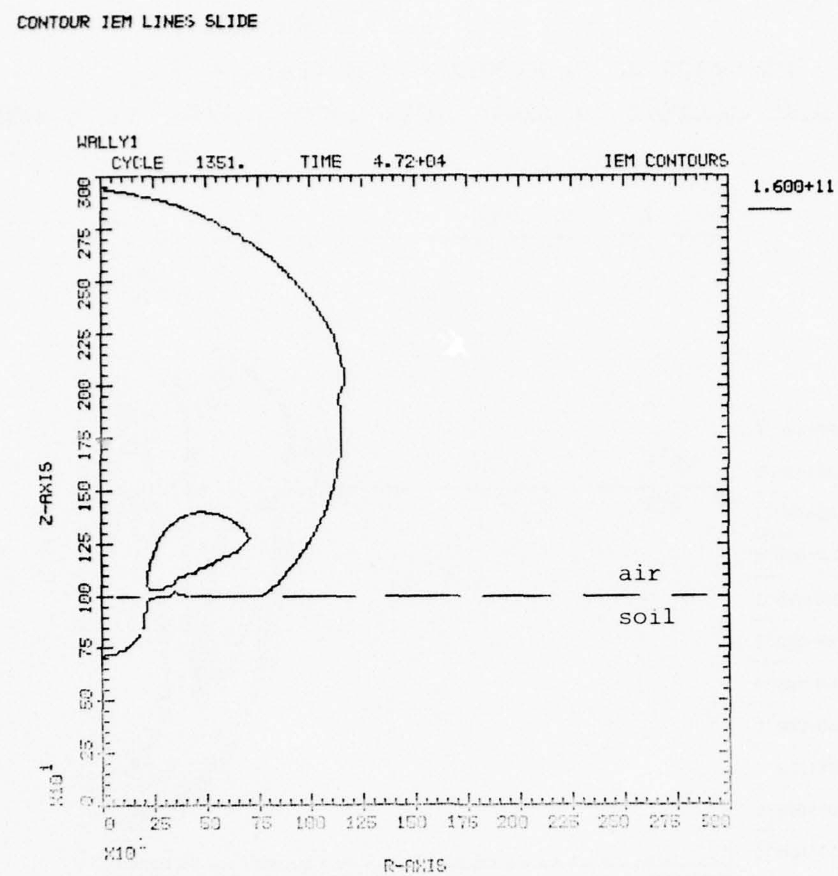

FIGURE A.22 RAD9 CALCULATION, 1-KT AT 0.5-METER DEPTH, t = 0.472 MSEC; 1.6×10^{11} ERGS/GM INTERNAL ENERGY CONTOUR

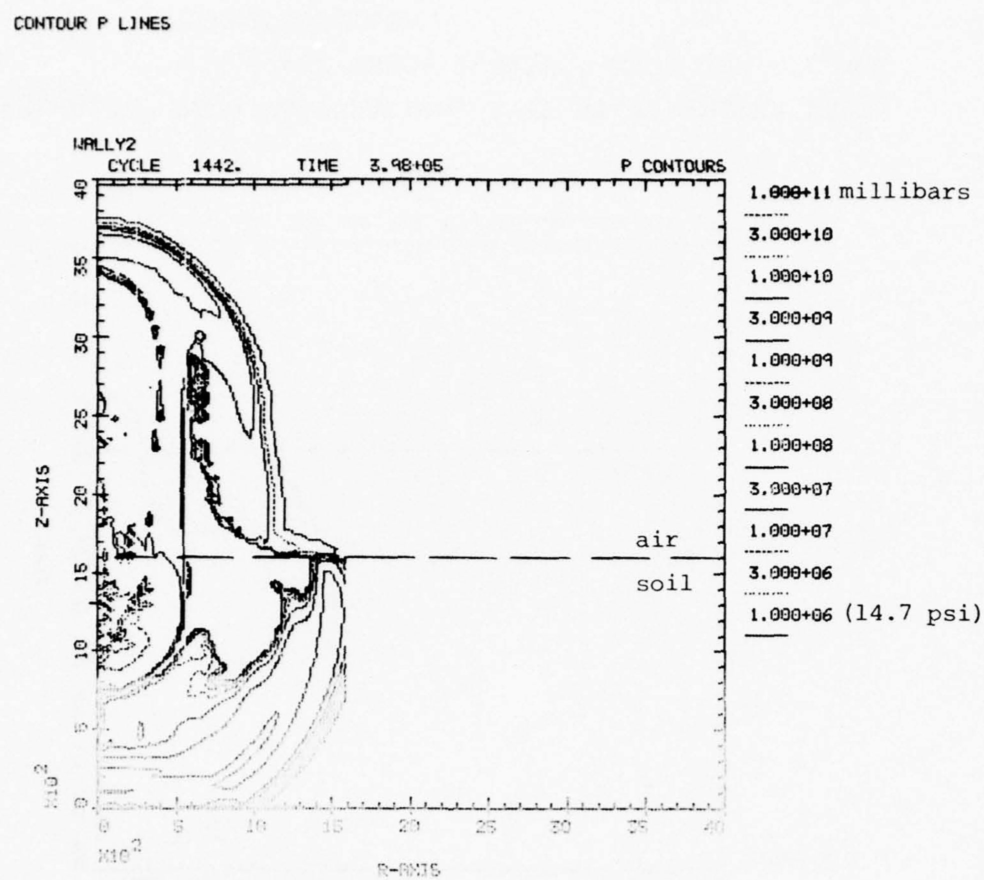

FIGURE A.23 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, t = 3.981 MSEC; CONTOURS OF CONSTANT PRESSURE

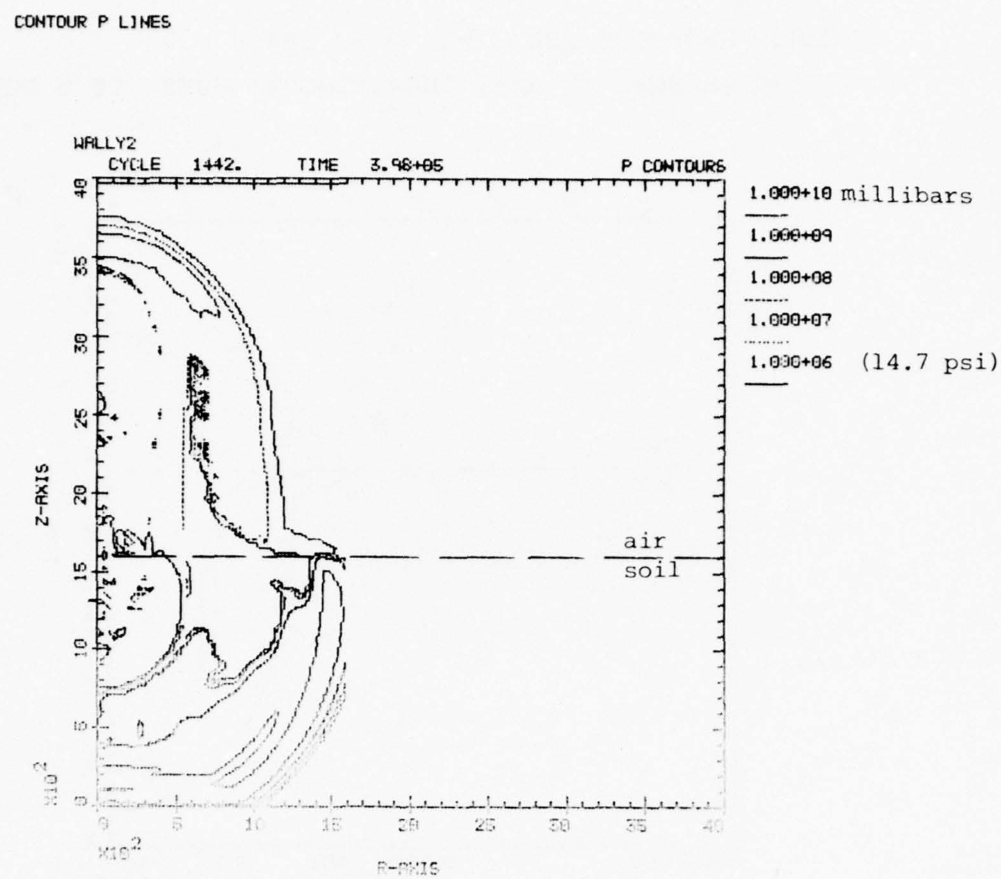

FIGURE A.24 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, t = 3.981 MSEC; CONTOURS OF CONSTANT PRESSURE

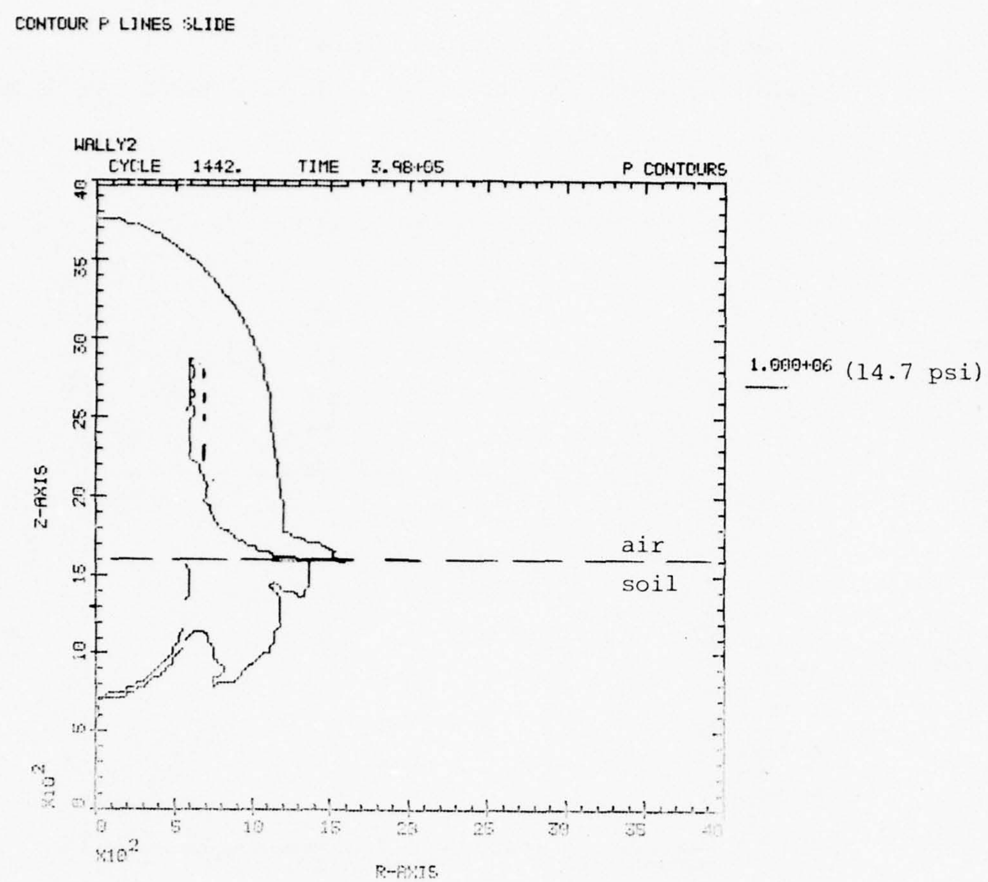

FIGURE A.25 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, t = 3.981 MSEC; 14.7 PSI PRESSURE CONTOUR

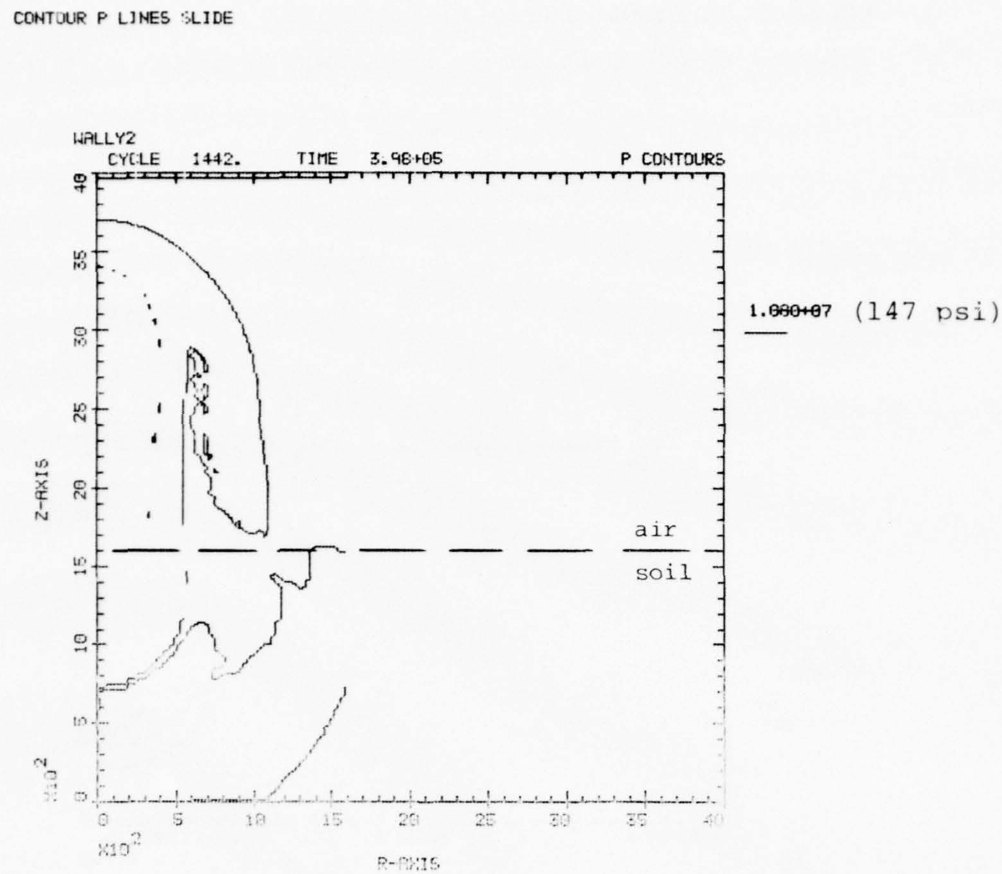

FIGURE A.26 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, t = 3.981 MSEC; 147 PSI PRESSURE CONTOUR

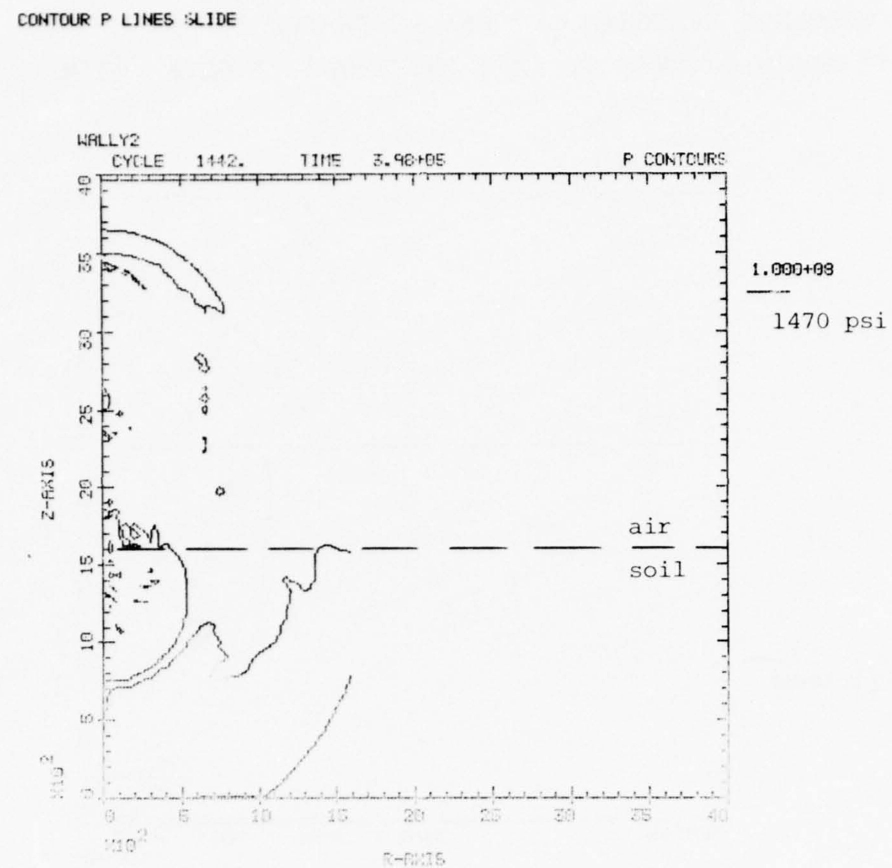

FIGURE A.27 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, t = 3.981 MSEC; 1470 PSI PRESSURE CONTOUR

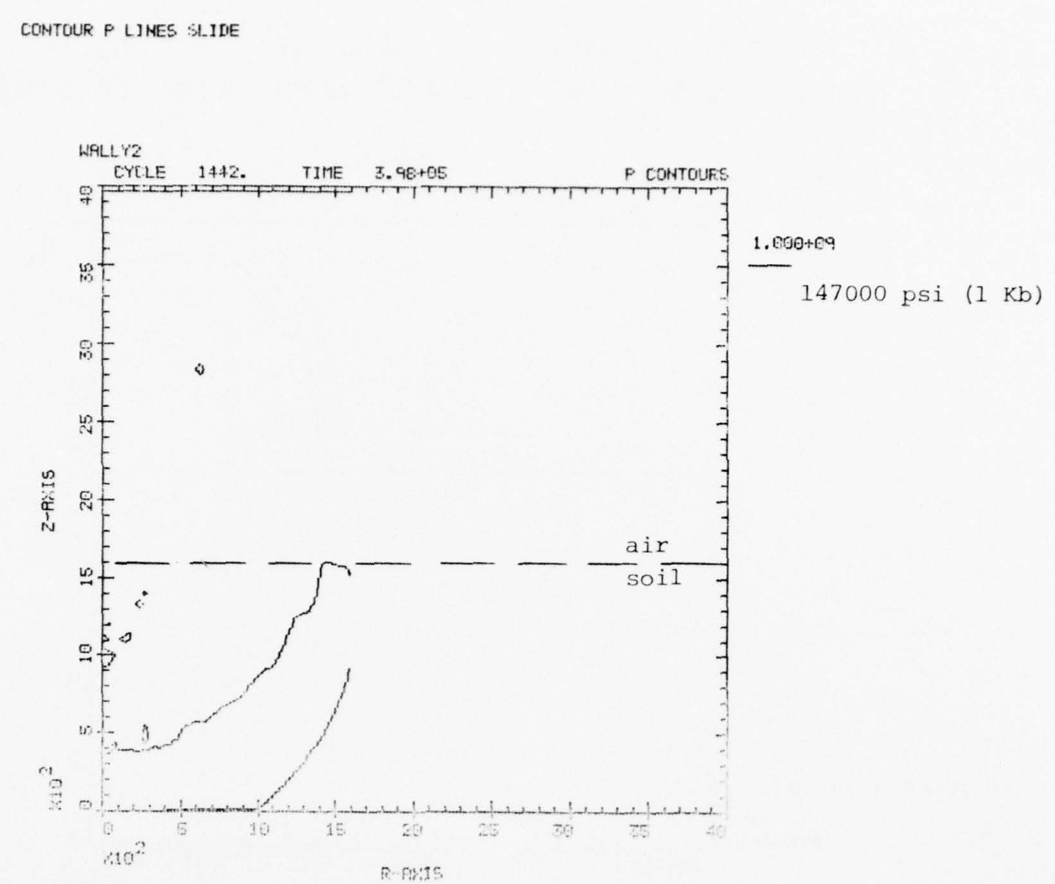

FIGURE A.28 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, t = 3.981 MSEC; 14700 PSI (1 KB) PRESSURE CONTOUR

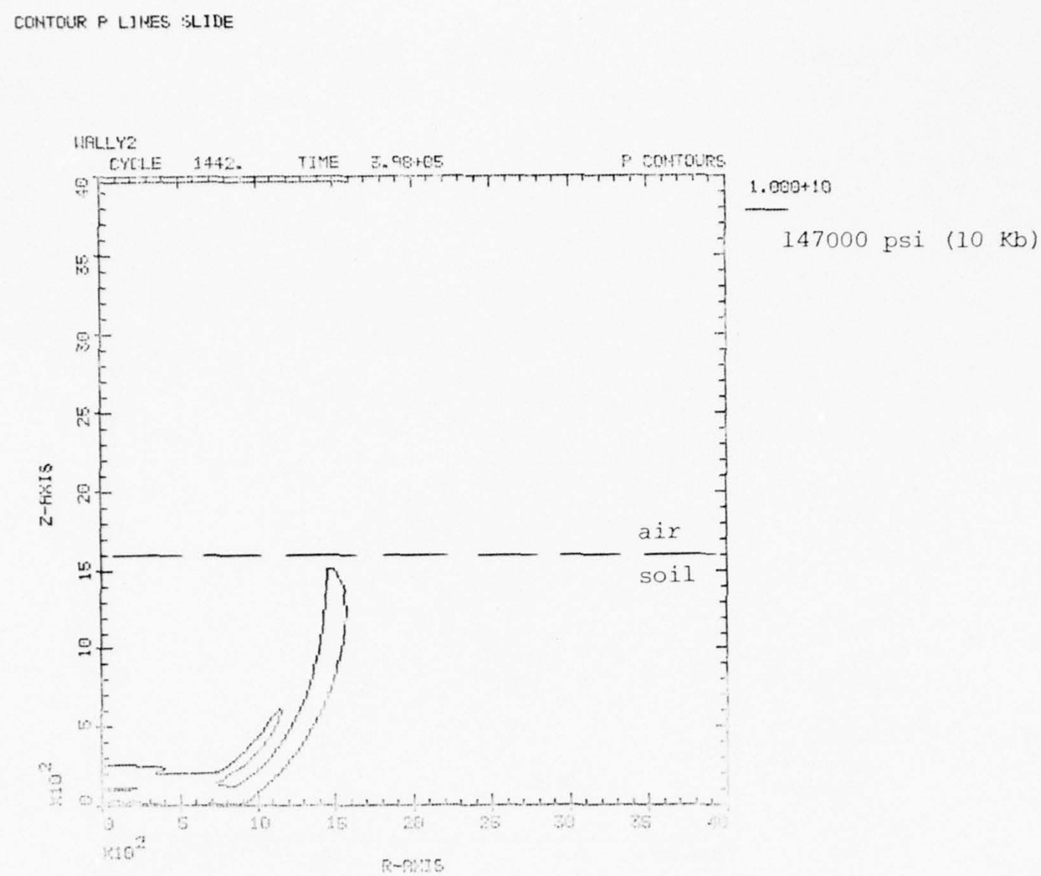

FIGURE A.29 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, t ≈ 3.981 MSEC; 10 KB PRESSURE CONTOUR

CONTOUR DEN LINES

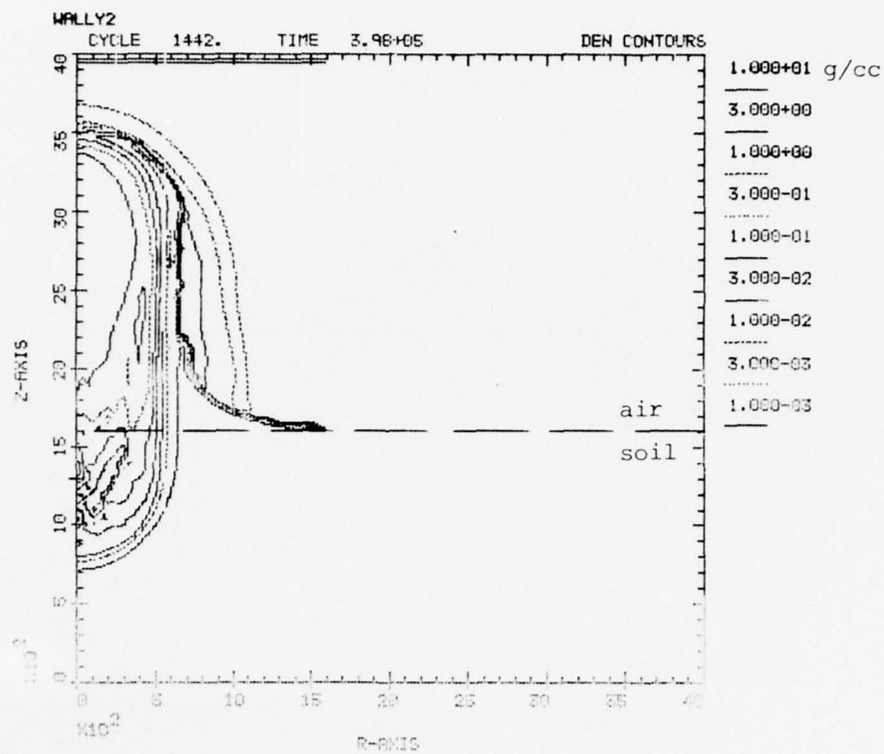

FIGURE A.30 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, t = 3.981 MSEC; CONTOURS OF CONSTANT DENSITY

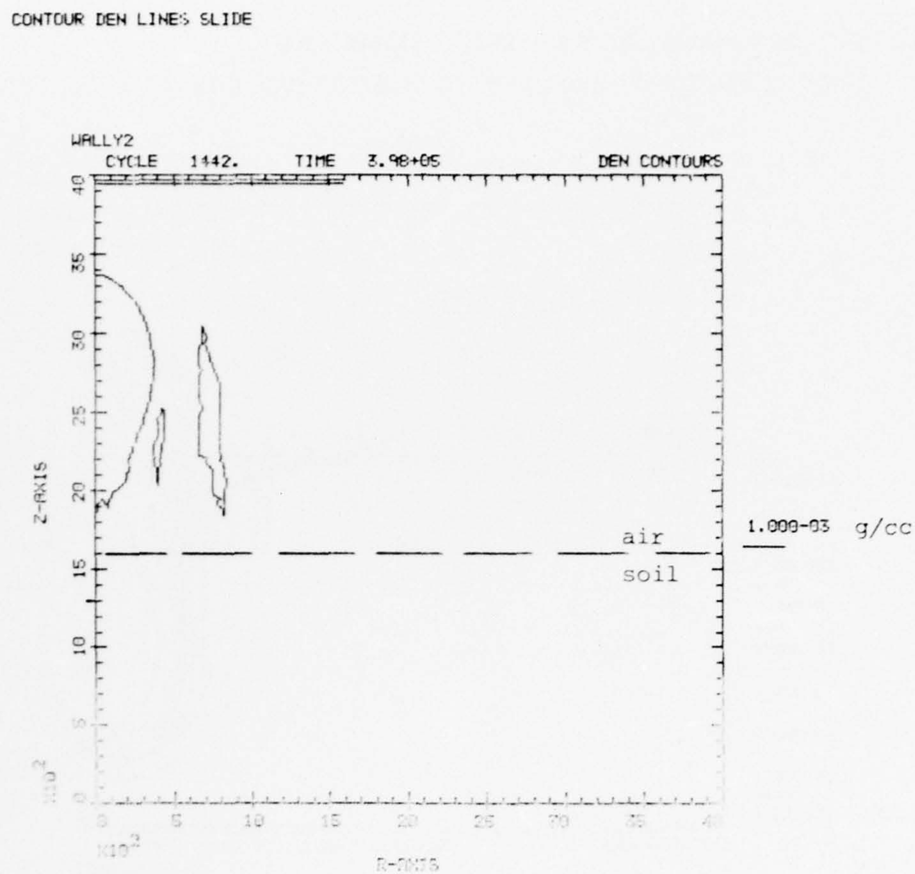

FIGURE A.31 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, $t = 3.981$ MSEC; 1×10^{-3} g/cc DENSITY CONTOUR

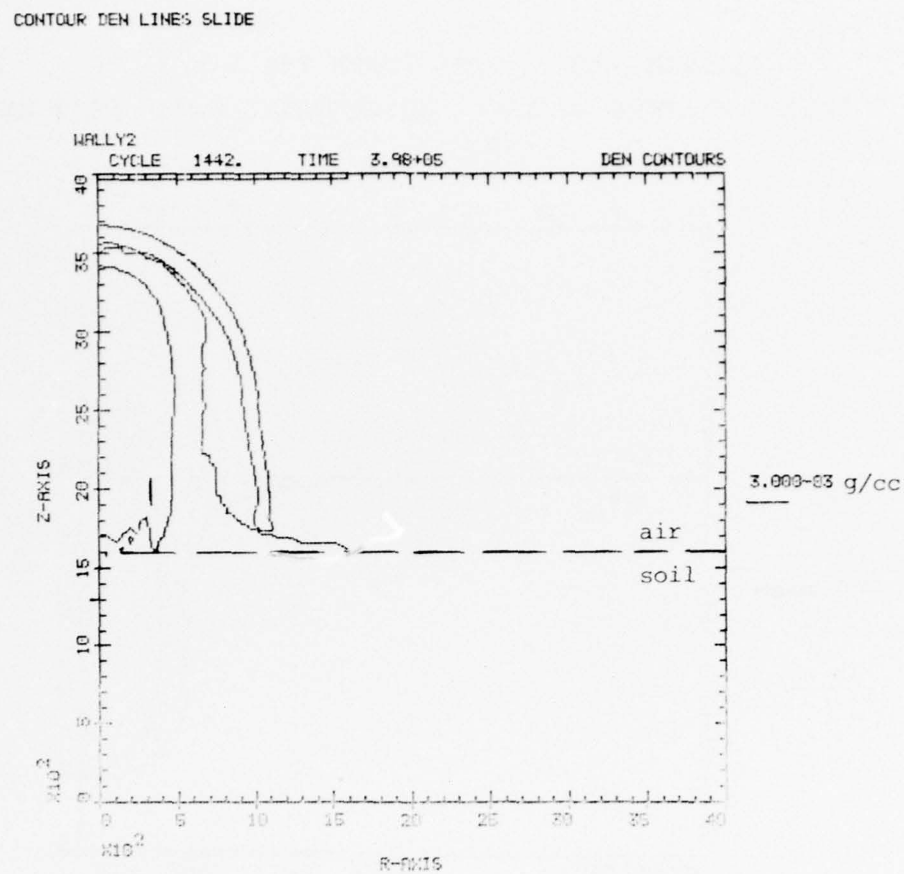

FIGURE A.32 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, $t = 3.981$ MSEC; $3\text{x}10^{-3}$ g/cc DENSITY CONTOUR

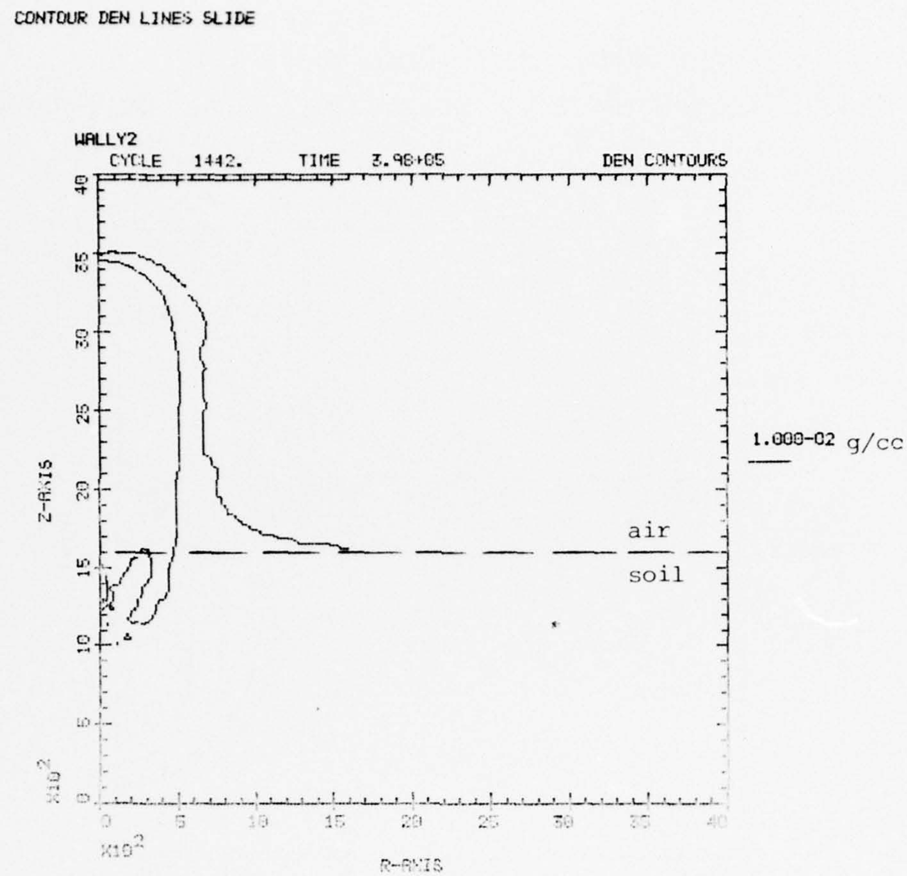

FIGURE A.33 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, $t = 3.981$ MSEC; 1×10^{-2} g/cc DENSITY CONTOUR

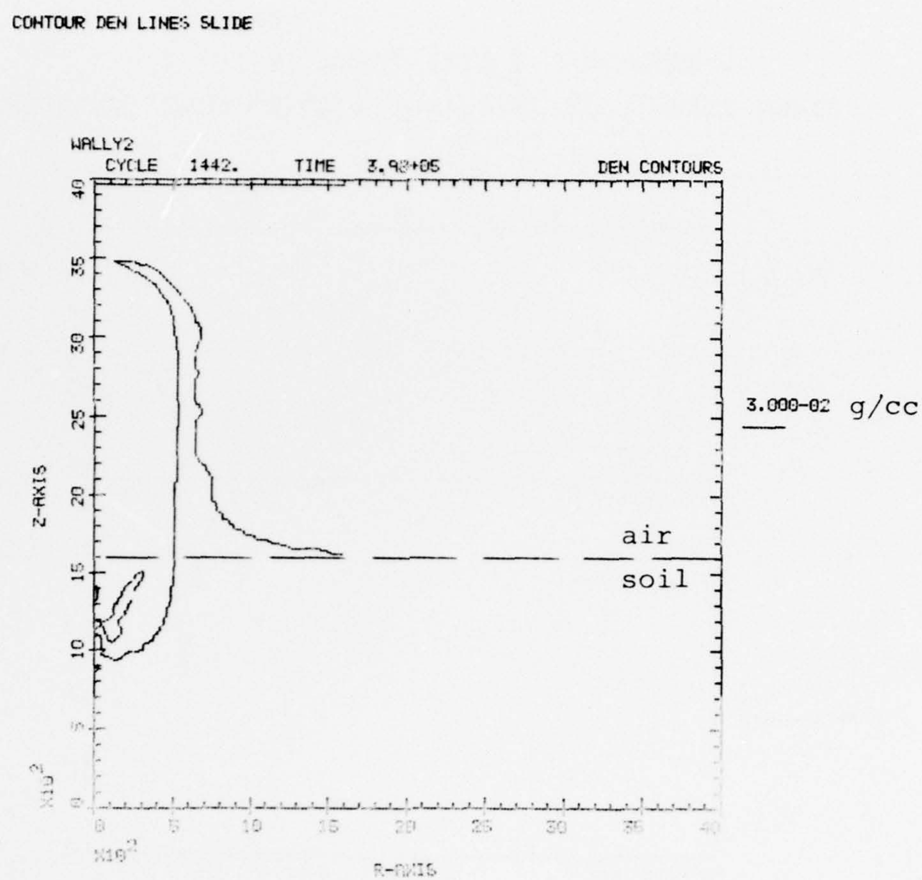

FIGURE A.34 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, $t = 3.981$ MSEC; 3×10^{-2} g/cc DENSITY CONTOUR

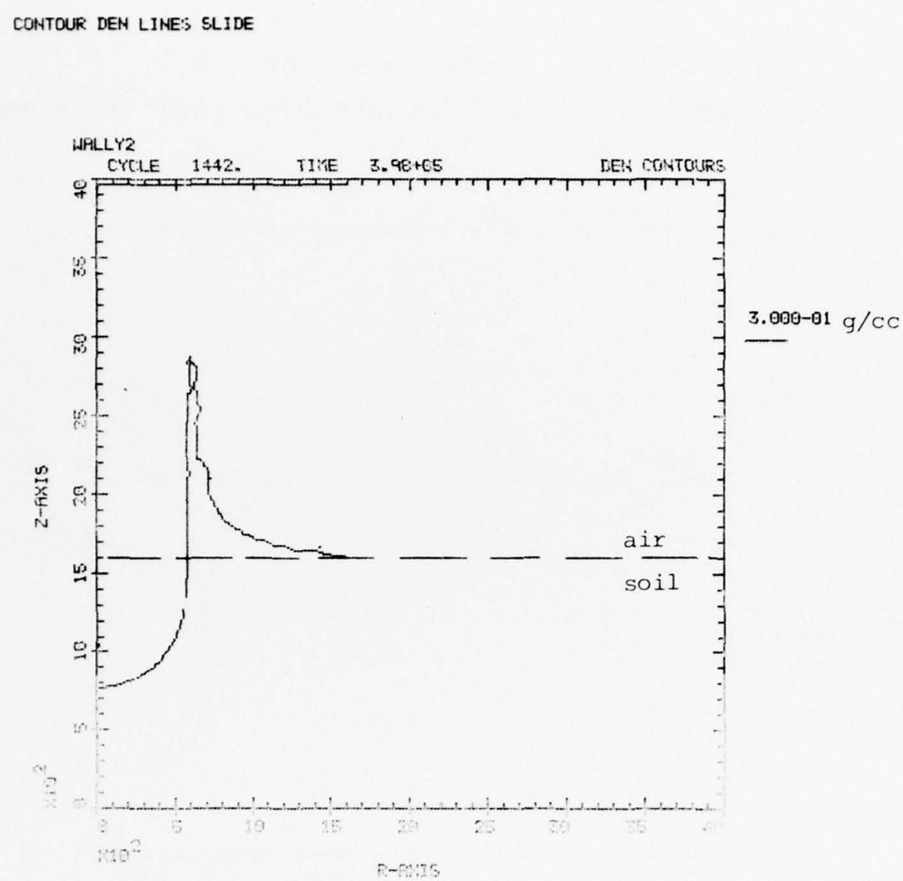

FIGURE A.35 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, $t = 3.981$ MSEC; 3×10^{-1} g/cc DENSITY CONTOUR

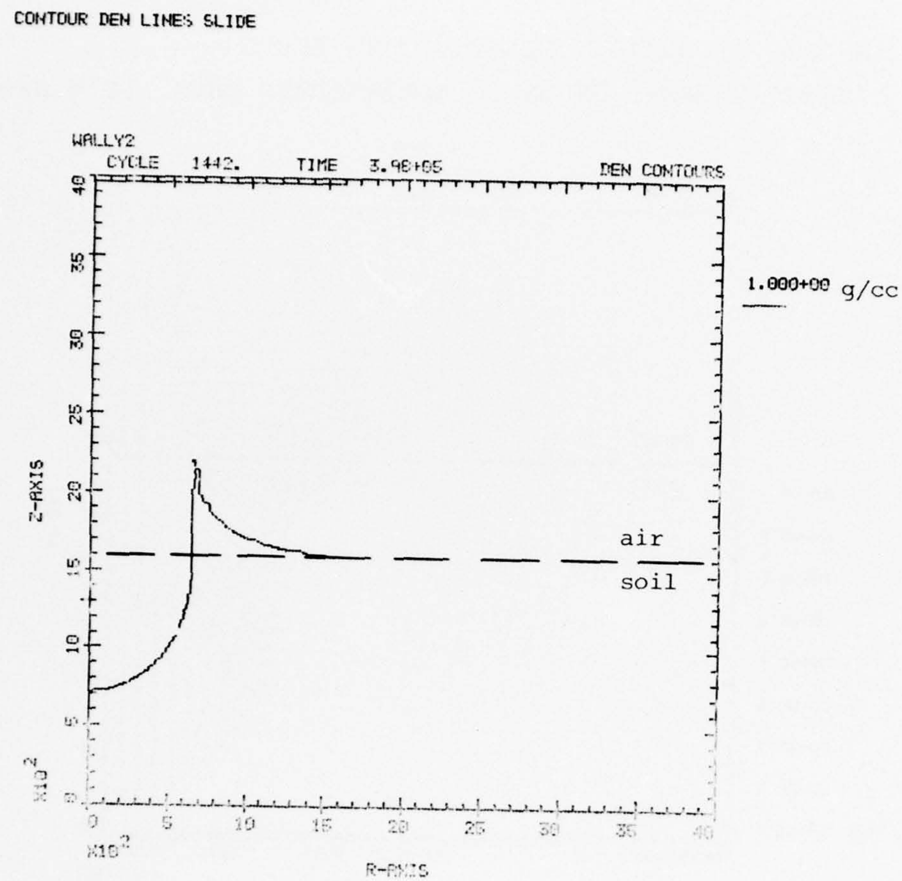

FIGURE A.36 RAD 9 CALCULATION, 1-KT AT 3-METER DEPTH, t = 3.981 MSEC; 1.0 g/cc DENSITY CONTOUR

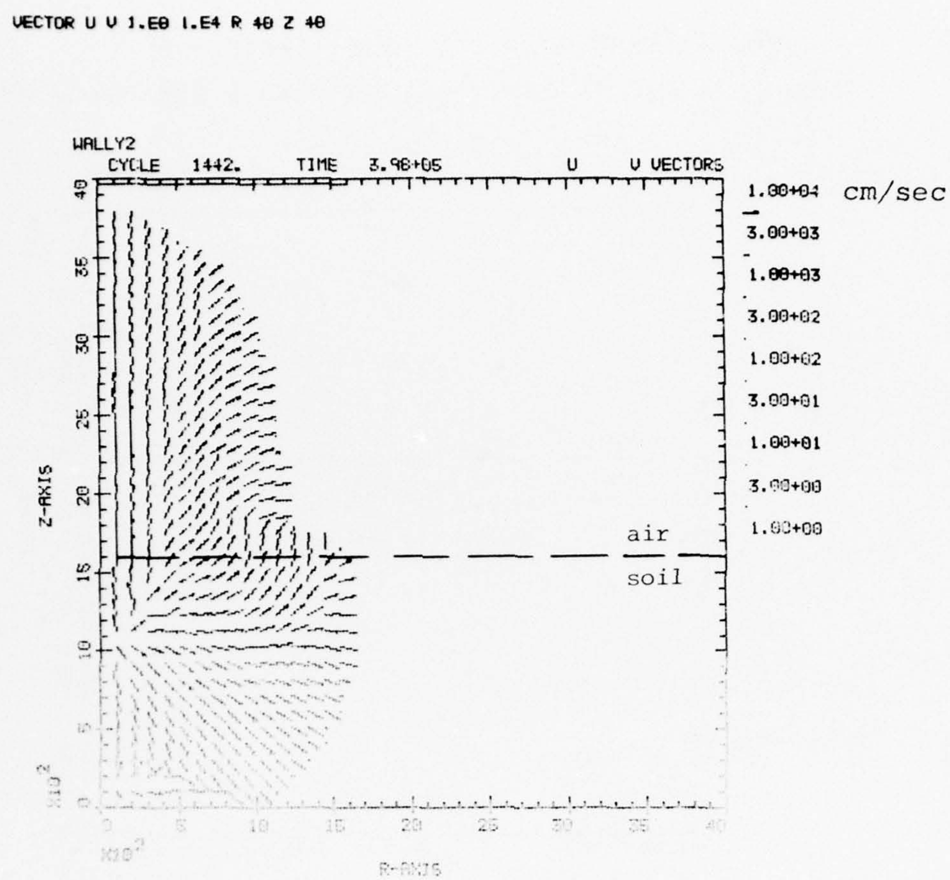

FIGURE A.37 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, t = 3.981 MSEC; PARTICLE VELOCITY VECTORS (CM/SEC)

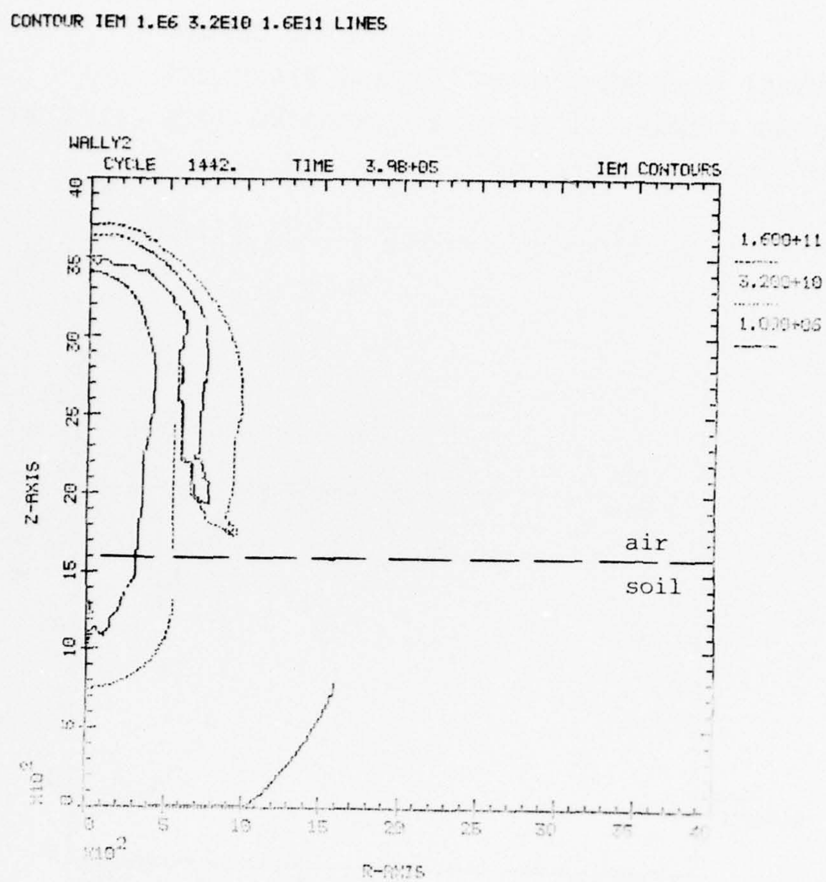

FIGURE A.38 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, t = 3.981 MSEC; CONTOURS OF CONSTANT INTERNAL ENERGY

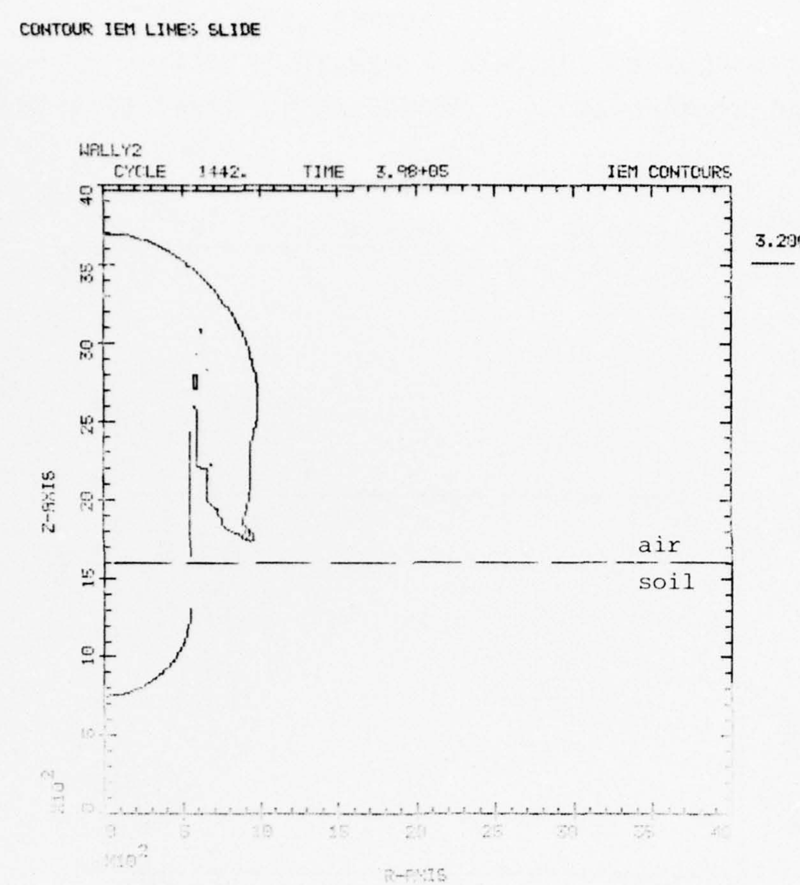

FIGURE A.39 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, t = 3.981 MSEC; 3.2×10^{10} ERGS/GM INTERNAL ENERGY CONTOUR

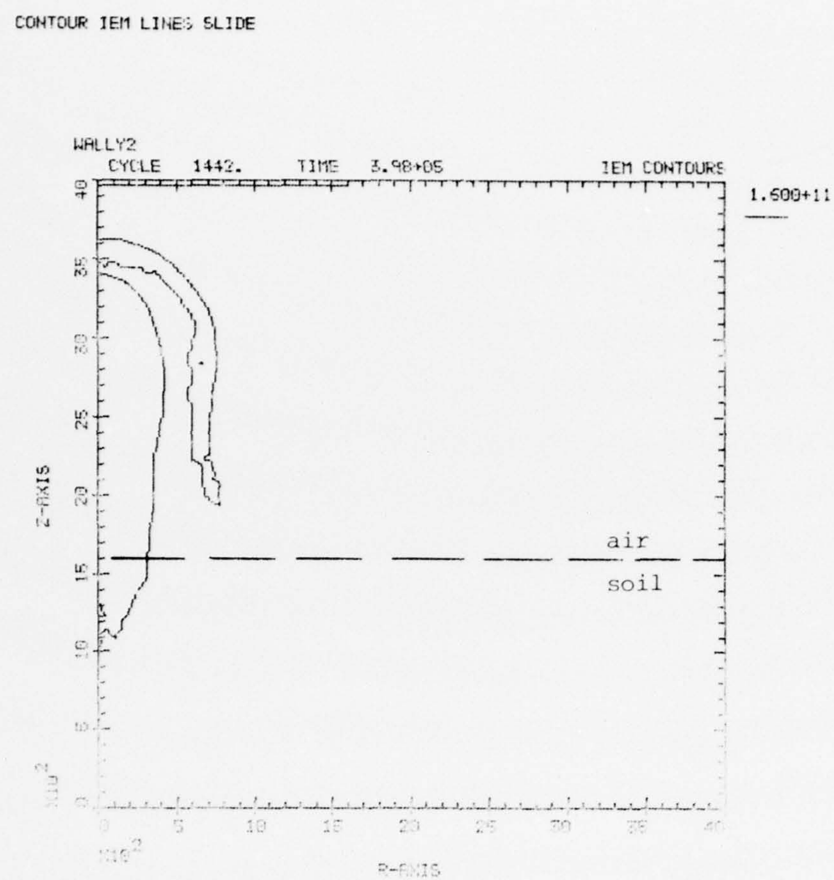

FIGURE A.40 RAD9 CALCULATION, 1-KT AT 3-METER DEPTH, $t = 3.981$ MSEC; 1.6×10^{11} ERGS/GM INTERNAL ENERGY CONTOUR

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ATTN: Arthur Miles Hohorf for George Duval

Weidlinger Assoc. Consulting Engineers
ATTN: J. W. Wright
ATTN: Melvin L. Baron

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ATTN: J. Isenberg

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